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A MODIFIED UNIVERSAL STAGE

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SUMMARY

The purpose of this paper is to describe a microscope method for determining principal refractive indices by the immersion method using the universal stage. From any one grain of a biaxial mineral of moderate birefringence, regardless of its original orientation, it is possible to measure all three refractive indices. A new universal stage is described which permits the operator, after orienting a mineral in such a way that X, Y or Z is parallel to the axis of the microscope, to rotate the crystal on *either* of two mutually perpendicular horizontal axes. The last step is possible only on the modified stage. Also a water cell is described which makes possible the variable temperature control of the mount. The "Double Variation" procedure with the universal stage is outlined. If X (or Y or Z) is parallel to the axis of the microscope and two critical indices are determined, it may not be possible to rotate a full 90 degrees to obtain the third index. A procedure is given whereby the index is read at a chosen rotation and a graph gives the correct extrapolation for the 90 degree position. The attempt is made to avoid all graphical construction on the part of the operator and to present a procedure which is only a modification of the standard immersion methods so widely used in America. For the writer the universal stage, instead of being an accurate but time consuming instrument, has become a time saving instrument with added accuracy.

Recently in connection with some experiments on a new method of mineral refractive index determination which involves the combination of both temperature and wave length control,¹ the writer had reason to believe that the universal stage might be employed to advantage. But it seemed that the complexity of the manipulation of the standard stage is such that American petrographers probably could not be persuaded to use it. As an outgrowth of this realization a Leitz model of a Fedorow stage was modified by the addition of one more horizontal axis of rotation. The new axis is parallel to the east-west horizontal axis. The addition of this axis, although complicating the manufacture of the stage, very greatly simplifies the manipulation. The Bausch and Lomb Optical Company has already done considerable work toward the commercial manufacture of the stage as described in this paper.

¹ R. C. Emmons, *Am. Mineralogist*, Vol. 13, 1928, p. 504; *Am. Mineralogist*, Vol. 14, 1929, p. 414.

America's foremost petrographers have for more than twenty years pointed out the great advantages of the universal stage, but still this instrument is scarcely used in America, although in Europe it is employed extensively. There are, of course, several good reasons for its slow adoption in this country—two of these will be mentioned. First, the universal stage in its present form is admittedly complicated and certainly too involved for routine petrography. Second, the analysis of results obtained from universal stage observations involves lengthy and cumbersome graphical procedures which to quote F. E. Wright, have caused the stage not to be adopted "so rapidly and generally as might have been anticipated."²

The use of the standard universal stage requires time consuming manipulation and considerable indirect reasoning that does not appeal to the routine petrographer, who as a rule is more interested in direct observations. In the present article an attempt is made first to describe a modified universal stage and its manipulation, and second, to state a procedure which has been reduced to a simple routine almost as direct as the customary procedures and observations of the American petrographer.

I have experienced difficulty in instructing students in the use of the standard Fedorow stage for routine work, such as in the determination of feldspars. Accordingly it was with no small interest that I recently tried out the new model on a group of eight students selected from a class in petrography. It was highly gratifying to find that at the end of one hour's instruction the men were able to make certain routine tests, and they expressed genuine satisfaction with the simplicity of the manipulation of the new model. The great utility of the universal stage is of course unchallenged.

The one limitation of the standard universal stage which has been a source of considerable annoyance to me is the inability to rotate a crystal on two mutually perpendicular and horizontal axes after the crystal has been oriented with one of the axes of the optic indicatrix vertical. The reason for this lies in the fact that a rotation on the east-west horizontal axis is almost invariably necessary in order to bring one of the desired mineral axes into a vertical position and such a rotation inclines the only other horizontal axis (north-south) so that the plane of its rotation is no longer vertical. Accordingly in the modified stage there are two

² F. E. Wright, *Methods of Petrographic Microscopic Research*, p. 176.

horizontal east-west axes of rotation. Otherwise it is quite the same as the standard stage.

A detailed description of the recommended procedure is given below, but for those familiar with the universal stage the difference in manipulation (see Fig. 1) may be summarized as follows:—instead of making the selected vibration direction parallel to the N-S cross-hair, make it parallel to the E-W cross-hair and by suitable manipulation in the standard way, but using the inner E-W axis of rotation, make an optic symmetry plane parallel to the E-W nicol; that is, vertical. Now by rotation on the N-S horizontal axis one of the vibration directions, X, Y, or Z, two of which lie in this vertical symmetry plane, may be made parallel to the axis of

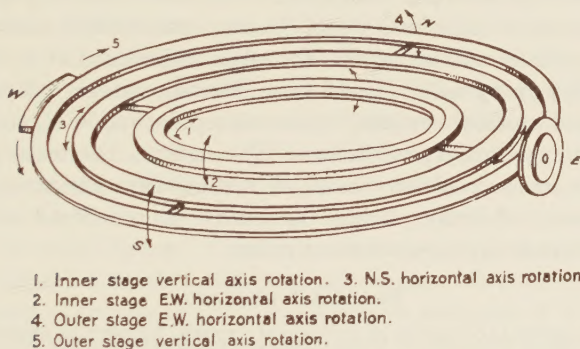


Figure 1. Diagrammatic representation of the modified stage showing the added inner E-W axis, and the rotational movements of all axes.

the microscope. In other words, the crystal in this way may be oriented for the universal stage. It now can be rotated in two mutually perpendicular and vertical planes on the two horizontal axes—both of which *are* horizontal. Furthermore, the actual time required to secure this position is but slightly greater than that required to make only one of the symmetry planes perpendicular and is equally simple to do. It is unnecessary to make two or three initial planes of symmetry parallel to a nicol, as is done in using the standard universal stage, and this affords a considerable saving of time. It is also unnecessary to graph information except for purposes of record and detailed accuracy, and to bridge the gap between two quite separate positions of the stage—a bridge which few American petrographers care to take the time to make. Moreover, it becomes a very convenient procedure both to test two sym-

metry planes from one position for optic axes, and to secure a position in which two known critical rays are being transmitted. It is also sometimes possible to test three symmetry planes and, therefore, to obtain three critical rays from one grain. Although it is impossible to obtain interference figures with the universal stage, still, these figures are not essential, and this limitation is not serious.

The manipulation of the universal stage is as complicated as many phases of crystal optics. The average student of petrography is very apt indeed on completing his course in fundamentals to forget a great many of them, even before his university training is completed. Possibly this situation, which unfortunately is quite general, also offers in part an explanation for the limited popularity of the use of the universal stage. In any case, a brief summary of the vibration directions within the optic indicatrix, as it bears on this problem, may well be given here. Biaxial crystals will be treated first and uniaxial crystals, whose manipulation on the universal stage is much simpler, will follow. Throughout, the main purpose here is to secure positions in which critical rays are transmitted, the ultimate objective being the study of powdered minerals. Thin section study is somewhat similar.

BIAXIAL CRYSTALS

In the optic indicatrix of a biaxial crystal there are three planes of symmetry which are mutually perpendicular. Each pair intersects, therefore, along a line which is perpendicular to each of the other lines of intersection. All three lines of intersection cross at a point which is the theoretical center of the figure.³ All the rays in which we are interested vibrate in these three planes since the optical constants of a biaxial crystal are studied only in crystal positions such that the axis of the microscope lies in at least one of the planes of symmetry. When this condition is fulfilled, the line of intersection of the other two planes is perpendicular to the axis of the microscope. This line of intersection is always one vibration direction of the light transmitted. When this line is parallel to one of the nicols the crystal is, of course, in a position of extinction. The other vibration direction lies in the plane of symmetry which includes the axis of the microscope; it is perpendicular to the first

³ The initial study of the universal stage may be greatly simplified by cutting and folding a piece of paper so as to represent three mutually perpendicular planes. This model may be rotated with the stage in the following discussion.

and also perpendicular (or nearly so) to the direction of propagation of the transmitted light.

Normally a crystal fragment or thin section of a crystal suitably mounted on the microscope stage is so oriented that the axis of the microscope lies diagonally in one of the indicatrix octants and not in one of the planes of symmetry. The first step in orienting the grain is to make one of the planes of symmetry parallel to one of the nicols. To do this two rotations of the stage are needed. Let us first, for the sake of simplicity, review the construction of the stage and indicate a suitable terminology.

The modified stage has six axes of rotation which, from the center out, are as follows:⁴ First, a *vertical inner stage rotation axis* (See Fig. 1). This is used to turn the grain to extinction. Second, an *inner east-west horizontal axis*. This is used to tilt the grain after extinction is reached in order to bring the first optic symmetry plane into a position parallel with the E-W nicol. Third, a *north-south horizontal axis*. This is used to bring one of the critical vibration directions which lies in the first selected optic symmetry plane into a position parallel with the axis of the microscope. It is also used to search the first selected symmetry plane for optic axes as shown in detail below. Fourth, an *outer east-west horizontal axis*. The graduation on this axis carries a vernier. It is used to search the second optic symmetry plane for optic axes and it is also used to measure the optic angle in either plane, if the optic plane is identified as one of them. Fifth, a *vertical outer stage rotation axis*. This is used to rotate the first optic symmetry plane into a north-south position in case it should be found to be the optic plane. This makes it possible to measure V or $2V$ on the vernier scale. Berek uses this rotation to measure the optic angle indirectly. Sixth, the rotation of the microscope stage, or better still as on some microscopes, the *rotation of both nicols* simultaneously. This is used when making the actual measurement of the optic angle. The nicols are rotated to the 45 degree position which gives the sharpest extinction when an optic axis is brought parallel to the axis of the microscope. The order in which these rotations are described is essentially the order in which they are used.

Now to return to the selected grain the orientation of which is

⁴ The reference names for these axes as given here are not standard but are ones that I have suggested. They seem to me to be short and more obvious than numbers as used by Berek and others. In giving instruction to a limited number of students in this field these names have proved satisfactory.

not known, but is safely assumed to be such that X, Y, and Z are all inclined to the axis of the microscope and to the stage of the microscope. Using the vertical inner stage rotation, turn the grain to a position of extinction. This position will suffice as a starting point without the next step, but the procedure is somewhat simplified if the next step is taken. Next rotate separately on each of two mutually perpendicular horizontal axes of rotation, and note on which axis the grain departs least from extinction. Then rotate 90 degrees if necessary on the vertical inner stage axis to make a rotation on the north-south horizontal axis depart least from extinction. Now the grain is so oriented that when all horizontal axes read zero the steepest optic symmetry plane strikes in a general east-west direction and dips either north or south. The steeper the dip the less is the departure of the strike from a true east-west direction.

To make this symmetry plane parallel to the east-west nicol the procedure is as follows: Rotate a few degrees on the inner E-W horizontal axis in either direction. This causes the crystal to depart from extinction. Bring the crystal back to extinction by a small rotation on the inner stage vertical axis. Now if the first of these two rotations was made in the right direction the crystal in its new position may be rotated on the N-S horizontal axis and the departure from extinction will be less than before. If the departure from extinction is greater than before then this first rotation was in the wrong direction. In other words, it must be determined empirically whether the first selected optic symmetry plane is dipping north or south. Having decided in which direction to rotate the crystal on the inner stage E-W horizontal axis, then by successively rotating on this axis a few degrees, returning the crystal to extinction by a rotation on the inner stage vertical axis and testing by a rotation on the N-S horizontal axis, the first selected optic symmetry plane is made parallel to the E-W nicol. Parallelism is obtained when a rotation on the N-S horizontal axis does not disturb extinction. This operation is a "cut and try" procedure and is, therefore, the most difficult and unsatisfactory feature of the universal stage manipulation. However, with a little practice it requires very little time. We have now made the first optic symmetry plane parallel to the E-W nicol. We may safely assume that the other two symmetry planes, which we know are striking true north and south, dip one east and one west. There is only a theoretical possibility that one is vertical and one horizontal.

The next step is to make one vertical and one horizontal, or in other words, make two of the directions X, Y, Z horizontal, and one parallel to the axis of the microscope. Attention is called to the fact that the verniers of both of the other horizontal axes (i.e. the outer E-W and the N-S horizontal axes) still read zero. The ray which is vibrating parallel to the N-S nicol is one of the critical rays vibrating parallel to X, Y, or Z. The N-S horizontal axis is parallel to this vibration direction. Therefore, this axis (N-S) lies in each of the other two optic symmetry planes and a rotation on it in one direction tends to make one of these planes parallel to the N-S nicol, and in the other direction to make the other plane parallel to the nicol. But the grain is now at extinction which is the only criterion under the circumstances for knowing when an optic symmetry plane is parallel to the nicol. Therefore, on the outer stage E-W horizontal axis rotate a few degrees thereby causing the crystal to depart from extinction. Then rotate on the N-S horizontal axis (now slightly inclined) in either direction until extinction is secured. Now return the outer stage E-W horizontal axis to its zero reading and the crystal is oriented for the universal stage. The last rotation on the N-S horizontal axis can commonly be made either way. It can be made in one direction only if one of the other optic symmetry planes that is being sought is dipping steeply. Then a small rotation in one direction brings extinction and a large rotation in the other direction may fail to bring extinction. If it is possible to obtain extinction both ways, then all three symmetry planes may be made parallel to the nicols, two at a time; also, all three rays vibrating parallel to X, Y, and Z, may be transmitted, two at a time.

Knowing the orientation of the grain, the operator turns next to a determination of the optic plane and a measurement of the optic angle. Rotate the nicols to the 45 degree position, (or if the microscope is not equipped for the simultaneous rotation of the nicols, rotate the stage of the microscope). Then rotate the crystal from its oriented position, first using the outer stage E-W horizontal axis and second the N-S horizontal axis. If on either rotation extinction is reached, then this extinction position is an optic axis position. Since the nicols are at 45 degrees to the planes of symmetry, which in turn include the only possible vibration directions for the orientations being used, then it is only when the direction of transmission is parallel to an optic axis that the plane of vibration

of the polarizer is not rotated in the mineral, and extinction results. The optic axis position may be checked readily by rotating either the nicols or the stage of the microscope—extinction should persist. Measure the angle of rotation required—either it or its complement (corrected for refractive index as shown below) is V . If the optic plane proves to be the E-W (i.e. the first selected) symmetry plane then it is well to rotate the mount through 90 degrees on the outer stage vertical axis. Then the symmetry plane is in the N-S position and V may be measured on the vernier scale of the outer stage E-W axis. If neither of the vertical symmetry planes is the optic plane then the horizontal plane must be. It may or may not be possible to make this plane vertical. If not, then a slight movement of the grain is likely to be sufficient to give a more favorable orientation. The entire procedure must of course be repeated again but with very little practice it should take only a few minutes.

Unless the mineral is one of low birefringence readings of quite satisfactory accuracy⁵ may be obtained for $2V$ by direct measurement if the proper conditions required for the illumination of the stage are observed. These are given in a later paragraph. If for any reason the optic angle is not measured directly, it can be easily calculated from the determination of refractive indices toward which this procedure is leading. Or $2V$ may be obtained from Wright's graph reproduced here.

UNIAXIAL CRYSTALS

Uniaxial crystals may be oriented much more simply. For any position of extinction of a uniaxial crystal the plane of vibration of one of the nicols includes the optic axis of the crystal. If then the crystal is rotated on an axis perpendicular to this plane, the optic axis must still remain in the plane—or, the crystal in other words, will remain at extinction. If, on the other hand, the crystal is rotated on a horizontal axis which lies in the plane to which the optic axis is parallel, then the crystal will depart from extinction unless the optic axis is either parallel or perpendicular to the rotation axis. For otherwise, the optic axis is rotated out of a position of parallelism with one of the nicols.

In order to orient a uniaxial crystal, this line of reasoning may be reversed. Turn the crystal to extinction on the vertical inner stage

⁵ Wright describes a method that is still more accurate but quite lengthy and tedious. It consists in plotting the optical curves of Fedorow in projection and locating the optic axis at the midpoint of intersection. *Idem*, p. 179.

axis. Rotate on first one horizontal axis, then the other perpendicular to it. On one of these rotations the crystal will remain at extinction. The optic axis lies in the plane that is perpendicular to this axis of rotation. There are two theoretical possibilities that the crystal will remain at extinction on both rotations—the optic axis is either horizontal or vertical and, therefore, on either rotation it is parallel constantly with the vibration plane of a nicol. If the optic axis is horizontal, the crystal will show its maximum birefringence in the 45 degree position, and if vertical, it will show no birefringence in the 45 degree position.

The recommended procedure, then, is to select a grain of rather high birefringence. Turn to extinction. Rotate on each of the two horizontal axes in turn and note on which rotation the crystal remains at extinction. Make this the N-S axis by a 90 degree rotation if necessary on the inner stage vertical axis. Then rotate slowly on the N-S axis in one direction until it is possible to rotate on the E-W axis without departing from extinction. If a crystal of relatively high birefringence was selected, then only the position of maximum birefringence can be reached, that is, it is possible to make the optic axis horizontal but probably not vertical. However, the vertical position is not needed except to test for a small optic angle. In the horizontal position both of the rays wanted are transmitted.

UNIVERSAL STAGE CONDITIONS

In general all crystals are oriented on the basis of extinction. To recognize an extinction position accurately is critical. As pointed out by Wright and others the correct position is not always the darkest as it would be for perfectly parallel light but it is a position of comparative darkness, the intensity of which does not change on the various selected rotations. Some prefer to insert a sensitive tint plate over a mineral at extinction, reduce the ocular diaphragm to exclude other minerals and to note changes in the sensitive tint as a test of extinction.

The conditions required for universal stage work are given in most modern texts on the subject. For minerals of high birefringence fewer precautions are necessary. But since most minerals commonly handled do not have high birefringence, it becomes necessary to employ added refinements of procedure for which we are largely indebted to Berek.⁶ The light should be as nearly paral-

⁶ M. Berek, *N. Jarb. Min., Beil. Bd.*, XLVIII, 1923.

lel as possible. To obtain this the diaphragms below and above the polarizer should be closed. Also, the diaphragm in the objective, if one is available, should be closed to exclude reflections, but quite satisfactory results can be obtained without this. With these diaphragms closed an intense source of light is needed for which an arc lamp serves well. If monochromatic light is employed from a monochromator, then the diaphragms need not be closed as other conditions supply the parallelism required. In my own work, in which I employ the universal stage almost exclusively in connection with the double variation method, a conveniently placed swing-out mirror between the arc lamp and monochromator serves to illuminate the microscope with either monochromatic light or the direct beam of the arc lamp. A low power objective is used—Nos. 1 or 2, or 32 or 36 mm.

The stage should of course be properly centered so that the three vertical axes coincide and the three horizontal axes are properly aligned with the nicols or cross hairs. To check the alignment of the horizontal axes the simplest procedure is to raise the objective until it is focused upon the surface of the upper hemisphere, then rotations on the horizontal axes should cause dust particles in focus to move parallel to the cross hairs.

Directions of light transmission within mineral grains mounted on the universal stage are modified on entering the upper hemisphere in quite the same way that these directions are modified on passing into the air from a microscope slide. If the mineral has a refractive index greater than that of the upper hemisphere, then the apparent direction of transmission makes a greater angle with the perpendicular to the inner stage than does the true direction of transmission. Hemispheres of two refractive indices are, therefore, provided for convenience. Apparent angles as read on the scales of the horizontal axes of the universal stage are simply corrected by knowing the refractive indices of the hemisphere and of the mineral. For this purpose a graphic solution is provided in most standard texts, designed after Fedorow. This is reproduced in Plate 1, with explanation. *Therefore, all vertical angles as read on the arcs of the universal stage must be corrected by this diagram to obtain a true figure.* There is here also the added advantage over thin sections that for this correction in working with powdered material the exact indices are known. It is sometimes advantageous when a large angle is to be read to use a high index hemisphere, even on a

mineral of comparatively low index, as this decreases the apparent angle.

TEMPERATURE CONTROL

In order to apply the principles of the double variation method of mineral determination variable temperature control of the mount is required. To accomplish this a special water cell has been designed for the universal stage, and is intended to be connected in series with the water circuit of the refractometer. The cell is shown in Figure 2. It consists of a metal disk in the center of which is mount-

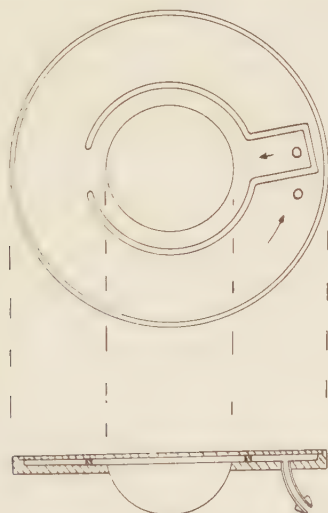


Figure 2. Water cell for the Universal Stage to be connected in series with the refractometer and to give controlled temperature of the immersion medium in which the crystal being studied is mounted.

ed the lower hemisphere. This constitutes the lower side of the cell. The upside is the central glass disc of the universal stage cemented to the metal disk along a raised margin. This is so adjusted as to leave a space between the metal and glass discs equalling in dimension the thickness of a microscope slide. It is through this space that water flows. The water is so directed by partitions within the cell that it flows directly across the center of the cell and returns around the margin. The intake and outlet tubes lead from the lower surface of the cell at one side. The cell is designed, of course, to fit in the place of the central glass discs of the stage. In making mounts no slide is used, but a cover glass is placed directly

on the upper surface of the cell, then the mount on this cover and another cover glass over this. The upper hemisphere is then clamped into position—all with suitable liquid contacts.

The method described by Ashton and Taylor was employed⁷ to determine the approximate temperature given by this cell. The "cold" junction of a thermocouple was placed in the refractometer and the "hot" junction was placed in the position of the mount on the cell. Readings were made on a Hoskins type H. A. "Thermoelectric" pyrometer. Readings are accurate to one-half a degree, and by interpolation, one quarter degree readings could be estimated. The readings indicate *differences* in temperatures between the liquid on the refractometer and that on the cell. The results follow:

ROOM TEMPERATURE 28°C. INDICATED TEMPERATURES READ ON THE
REFRACTOMETER THERMOMETER

At 27° after two minutes the temperature difference is 0°					
At 32.3°	" three	"	"	"	" 1°
At 32.3°	" five	"	"	"	" $\frac{1}{4}$ °
At 48°	" two	"	"	"	" 5°
At 48°	" five	"	"	"	" 1°
At 48°	" ten	"	"	"	" $\frac{1}{4}$ °
At 19°	" one	"	"	"	" 2°
At 19°	" three	"	"	"	" 1 $\frac{3}{4}$ °
At 19°	" five	"	"	"	" 1 $\frac{1}{2}$ °

The greatest difference in temperatures is found at the lower end of the scale rather than at the upper end. Not only is this true but the difference between the readings of the thermometer before the refractometer and that after this water cell, or any other water cell that I have used, is always greater at the lower temperatures. For the reading given above of 19° on the refractometer thermometer the corresponding reading on the second thermometer was 20°. The explanation is not obvious.

MOUNTING PROCEDURE

The procedure for using thin sections differs somewhat from that for work with powders. For thin sections place a drop of oil on the central glass disc and one on the top of the cover glass. The lower and upper hemispheres are then put in place, all contacts being made with oil. This procedure is standard. If the powder mount is

⁷ F. W. Ashton and W. C. Taylor. A Precision Method for the Determination of Refractive Indices. *Am. Mineral.*, Vol. 13, p. 411, 1928.

being made without the water cell described above, then a standard mount is made on a slide in a suitable liquid, and suitably covered. This is then mounted in the same manner as the thin section. If the water cell is used, then the powder is mounted between two cover glasses, the lower of which protects the central glass disc of the stage and cell and the upper protects the upper hemisphere. All contacts are made with the same liquid to avoid possible contamination. It has been stated that the upper surface of the cell is at a height on the stage equivalent to the upper surface of a glass slide resting on the standard central glass disc. Therefore, the powder mounted on the water cell, without a glass slide, is properly centered. Before placing the upper hemisphere, center a suitable grain. If ordinary oils are used, it is necessary either to use very few grains or to select a large one for observation, since the viscosity of the liquids is too low to support grains which are not held in position by the two cover glasses. The upper hemisphere must be clamped into position gently to avoid shattering grains. The particular immersion liquid used is one selected after a brief study of the mineral in the ordinary way. The greater facility of the daily procedure makes a cursory preliminary examination in this way highly desirable before attempting to use the universal stage.

THE DETERMINATION OF REFRACTIVE INDICES

The universal stage as used in Europe involves an amount of plotting that for the American renders its usefulness questionable because of the consequent time consumption. The procedure as outlined here leads to a determination of the principal refractive indices which American petrographers have consistently emphasized. The chosen method of comparative index determination is one of the two most widely used—the Becke line method.

The Becke line method when employed with the universal stage is outstandingly satisfactory. The commonly given text-book explanation that the Becke line results from light refracted at a surface between two substances that is perpendicular to the cover glass is doubtless satisfactory in some instances in thin section work. But most petrographers do not rely upon this explanation for immersed powders, rather, the effect results from the roughly lenticular shape of the grain. It is dependent for sharpness then, upon parallel light, an effect that is commonly gained by lowering the substage. The universal stage with the added distance between

the microscope stage and the mount is, therefore, particularly well suited to the Becke line method. And this is well borne out by experience, for a suitable mount on the universal stage gives a very strong Becke line with both white and monochromatic light, using either a No. 1 or No. 2 objective. When using white light, if the index of the mineral and liquid coincide for light of one wave length, then the dispersion of the rays is very marked unless the dispersion of the mineral is high, and nearly equal to that of the liquid. In short, the Becke line on the universal stage is at least as satisfactory as under the most favorable circumstances in standard use. Therefore, by employing monochromatic light of variable wavelength, a very accurate coincidence of indices can be secured.

It is almost always possible to rotate any grain on the universal stage sufficiently to make two of the symmetry planes of the optic indicatrix perpendicular; that is, to secure two of the principal rays. But it is not often possible to rotate from this position through a sufficiently large angle to secure the third principal ray. It is possible, however, to rotate through a considerable angle on the horizontal axis that is perpendicular to the plane of the vibration of the polarizer, though it may be necessary first to rotate 90° on the vertical outer stage axis. Now the refractive index may be measured in this new position. Knowing the refractive index before rotation on the horizontal axis and knowing the angle of rotation (corrected for refractive index-Plate I) and, therefore, the difference in index, it is possible to calculate the correct extrapolation to obtain the other principal index at 90° to the first. The greater the extrapolation the less accurate will be the final determination but, fortunately, it is usually possible to rotate through a considerable angle. To facilitate this detail of the procedure a graphical solution of this calculation is offered in Plate II.⁸ This diagram holds for any direction in a uniaxial crystal and for any direction of rotation within a plane of symmetry of a biaxial crystal. All angular measurements are made from principal positions.

Even though the double variation method of index determination is used, it is not always possible to bring about sufficient variation to reach the second principal index after the first has been determined. For such minerals of rather high birefringence if the

⁸ In constructing this graph I have consulted with R. W. Babcock of the department of Mathematics and have received considerable help from him on the proof of it.

second index on rotation on a horizontal axis perpendicular to the plane of vibration of the polarizer, approaches the first, which it must do half the time, then by the following procedure both the second and third indices may sometimes be determined. Rotate sufficiently to bring the second index within the range of the liquid and determine it. Then continue to rotate in the same direction as far as possible toward the third critical position and make another determination. Using the diagram (Plate II) after correcting for indices (Plate I), locate two points on the proper degree of rotation lines such that the vertical (or horizontal) intercept of the points indicates the proper index difference obtained from the two readings. Also both points must fall on the same inclined line. This inclined line gives at its extremities the total difference in index between the second and third principal rays. On the ordinate and abscissa can be read the difference in index between the principal indices and those determined. Therefore, the principal indices can be determined by simple addition and subtraction. If the mineral is one of high birefringence then this procedure fails.

Attention should be called to the fact that if the critical positions in which principal rays are transmitted are not accurately secured, the error in index is very small indeed as may be read from the diagram. But if the positions in which partial birefringence is read, especially near 45° , are not accurately determined then the error is considerable.

SUMMARY OF PROCEDURE

The mineral under study in powder form is cursorily examined on an ordinary glass slide to locate roughly its position on the refractive index scale. This information is used to select the proper "double variation" liquid for detailed study. A very few grains are then mounted between two cover glasses in the chosen liquid and are placed on the universal stage with the same liquid contacts, using the special water cell. One grain is centered and the upper hemisphere clamped in place. Using the direct illumination of an arc lamp, orient this grain so that X, Y or Z is parallel to the axis of the microscope. Then determine the indices of one or both of the rays transmitted, using temperature and wavelength variation. Rotate in a plane of symmetry to the third critical position if possible and determine the third index. Or, if this is impossible, then rotate as far as possible toward this position and determine the index.

By using Plate II extrapolate to obtain the correct index. The first index determined by the double variation method usually gives the dispersion curve for the mineral. For the other indices any one point on the dispersion curve, that is, a determination at any one wavelength is often sufficient since for many minerals the dispersion for the various rays is almost equal.

CONCLUSION

Nothing has been said of graphical methods of representing observations and drawing conclusions. Graphical methods have been worked out in great detail and have been adequately described in several languages. Wright's well-known book⁹ presents them in authoritative form for the English reader. It is doubtful if these methods which have been available for a long time will ever become popular in this country. This paper is intended to develop for the universal stage a technique that avoids graphical construction, and enables the operator to make direct observations of the kind the American petrographer is accustomed to make and to represent his results in the same terms that he has been using.

This paper is intended to be the third and final article by the writer on the subject of the "Double Variation Method of Mineral Determination." The two previous papers have been referred to in footnotes.¹⁰

There is especially one particular improvement which I should like to see made; an immersion medium is needed of essentially infinite viscosity at the temperatures at which the work is done. It must of course have high dispersion and a high thermal coefficient of refraction. It should be either variable in index by the addition of some other material or it should be one of a series. And it should be soft or melt at 50-70° C. I have tried water solutions of pectin, several gums, gelatin, etc., but none tried thus far have sufficient viscosity to support the smaller grains when the stage is tilted. Or, if they possess the necessary viscosity they are not suitably transparent. The resins have been suggested but do not seem entirely satisfactory. When a suitable medium is found it will avoid the necessity of using either a few grains or well sized grains.

⁹ F. E. Wright, *Methods of Petrographic Microscopic Research*, 1911.

¹⁰ While correcting proof of this article, Dr. T. Ito of the Imperial University of Tokyo visited our department. He informs me that he published in Japanese, *Jour. Geol. Soc. Tokyo*, 1924, a note descriptive of the use of the universal stage for immersion work.

By the method outlined here all three indices of refraction of any one grain of a biaxial mineral of moderate or low birefringence may be determined with both accuracy and comparative speed. The limiting factor lies in the index range of the immersion medium at the maximum suitable variation of temperature and wave length.

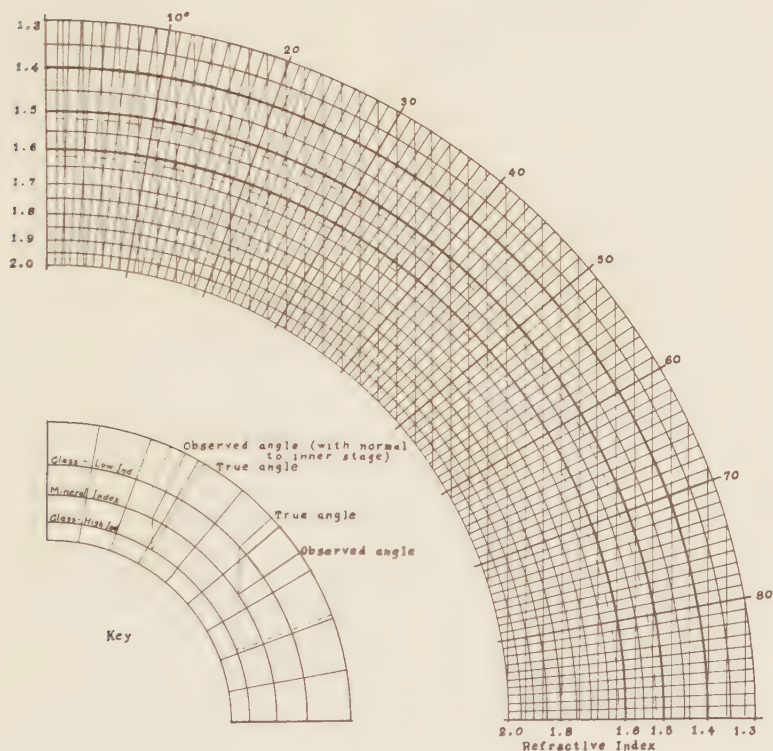


Plate I. Graphical Solution (after von Fedorow) of the equation $\sin i = n \sin r$. This is used to correct angular readings between the normal to the inner stage (or the section) and the direction of observation. The correction is based on first the index of the mineral, and second the index of the glass hemisphere that is being used. All angles to be used on Plate II must first be corrected on this graph or its equivalent. The procedure is shown in the key,—the observed angle as read on the scales is traced from the circumference to the circle which indicates the index of the mineral, from here along a vertical line (up or down) to the circle which indicates the index of the glass hemisphere, and from here radially to the circumference on which the true angle within the mineral is read,

Plate II. Graphical solution of the equation $\epsilon_1 = \epsilon\omega / \sqrt{\omega^2 \sin^2 \phi + \epsilon^2 \cos^2 \phi}$ and similar equations for the ellipses of the planes of symmetry of the optic indicatrix of a biaxial crystal. The large triangle will serve most practical purposes, the small triangle is intended for minerals of high birefringence. For the large triangle (and all ordinary work) no correction need be made for the position of the mineral on the refractive index scale. But the corrections given must be applied with the small triangle.

The use of the diagram may be outlined as follows:

Assume that a mineral has been oriented with X, Y or Z parallel to the axis of the microscope which can always be done and that two indices have been determined in this position by the double variation method. Assume further that it is impossible to rotate on a horizontal axis through 90° to either one of the other two principal positions, which is a common difficulty. Then rotate, with the grain at extinction as far as is conveniently possible on that horizontal axis which permits the greater rotation (up to 90°), and rotate the lower nicol (or the stage) if necessary to make its plane of vibration perpendicular to the axis of rotation. Note the amount of rotation on the horizontal axis and correct it according to Plate I. Measure the refractive index in the new position and find the difference in index between this value and that of the principal index already measured for the ray which vibrates in the same plane. This difference is found on the ordinate or abscissa as follows: If the rotation has caused a change from a greater to a smaller index, use the ordinate scale, if the rotation has caused a change from a smaller to a greater index, use the abscissa scale. Follow this value horizontally (or vertically) to the intersection with the proper degree of rotation line. Then follow the inclined line to its extremity where is indicated the total difference in index for a full 90° rotation. By simple addition or subtraction the third principal index may then be found.

For minerals of higher birefringence the smaller triangle is used similarly with this difference—if the index is not that for which the diagram was constructed, then a small correction must be applied. First determine the total difference in index as outlined for a 90° rotation. Select the proper small plat, follow the proper total “index-difference” curve to its intersection with the “degree-of-rotation” line (vertical) at which the reading was made. The correction is at the left.

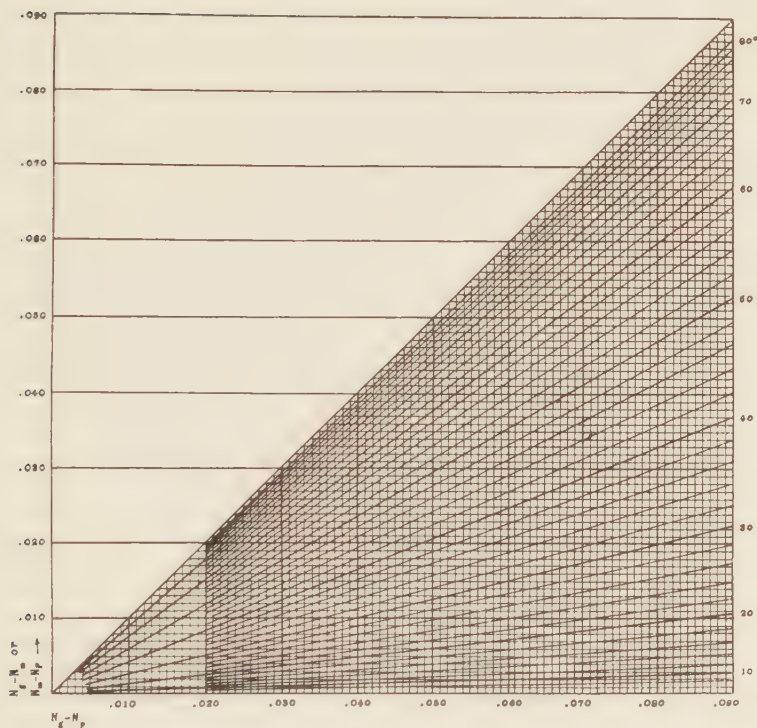


Plate III. Graphical solution (after Wright) of the equation $\sin^2 V = n_m - n_p / n_o - n_p$. Knowing by the procedure outlined the three principal refractive indices of a crystal, the optic angle can be obtained quickly by means of this graph. If the optic angle was measured directly on the universal stage as is frequently possible, then this gives a convenient check on the refractive indices. Total birefringence ($n_o - n_p$) is found on the abscissa and the partial birefringence ($n_o - n_m$ or $n_m - n_p$) is found on the ordinate. The inclined lines indicate V .

PLATE IV

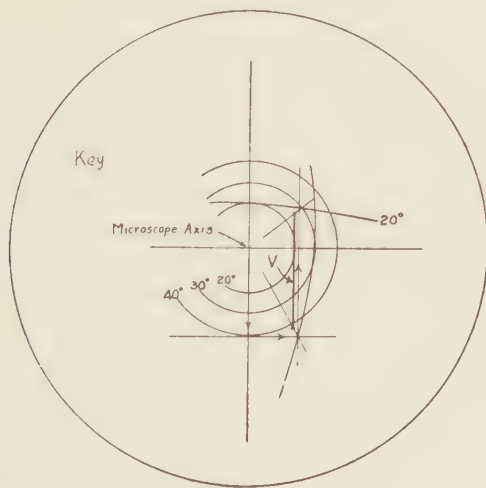
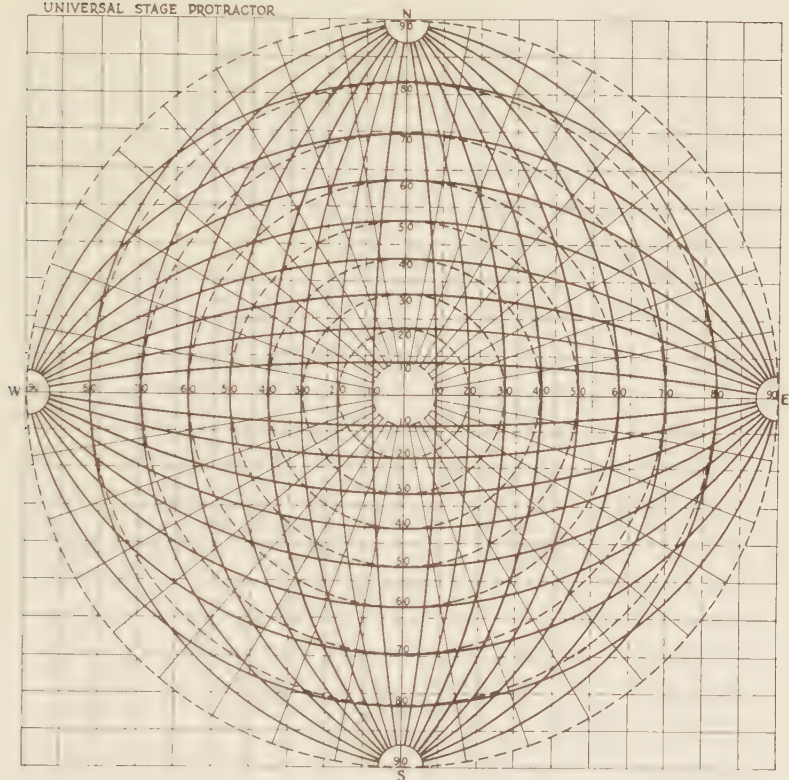
EXPLANATION: The purpose of this plate is to trace the movements of the perpendicular to the inner stage on the various rotations. It is a substitute for the Nikitin hemisphere. It gives at all times the angular distance of the perpendicular to the inner stage from the axis of the microscope. This angle is corrected for refractive index on Plate I. After making the corrections and locating the modified positions on this plate, then such angles as V or $2V$, and angles to be used on plate II may be read. This plate is a stereographic projection of angular rotations in divisions of 10° . For a great many determinations in which the angles of rotation are not large or the indices of the mineral and glass hemisphere do not differ greatly, it is unnecessary to use this plate as the error is small.

Example used in the key

Index of the mineral	1.70
Index of the hemisphere	1.60
Rotation on the inner E-W axis	40° S.
Rotation on the N-S axis	30° E.

These are typical rotations to make X or Z parallel to the axis of the microscope. Rotation on outer E-W axis to optic axis position -60° N. These apparent angular distances of the perpendicular from the microscope axis are corrected for refractive index on Plate I and replotted as shown. V is then read as 57° .

UNIVERSAL STAGE PROTRACTOR



PERICLASE FROM CRESTMORE NEAR RIVERSIDE, CALIFORNIA,* WITH A LIST OF MINERALS FROM THIS LOCALITY

AUSTIN F. ROGERS, *Stanford University.*

One of the most famous mineral localities in the United States is Crestmore, near Riverside, California. Here the Riverside Portland Cement Company has been quarrying metamorphic limestone and altered granodiorite which are used in the manufacture of cement at a nearby plant.

At this locality nearly 70 different minerals have been found since quarrying operations began about 15 years or so ago. A list of these minerals will be found on page 469. A few more have been reported but they are regarded as uncertain. Of the minerals listed, the starred ones which number seven (wilkeite, crestmoreite, riversideite, plazolite, jurupaite, merwinite, and foshagite) were new minerals described from this locality; of these merwinite has since been found at Larne, Ireland, and Velardena, Mexico (12). Probably only two other American mineral localities, Franklin Furnace, N. J., and Branchville, Conn., have furnished more new minerals than Crestmore.

Appended to this article will be found a bibliography of publications relating to the mineralogy of Crestmore. Article 3 by Professor A. S. Eakle of the University of California contains the best general account of the Crestmore minerals.

Periclase or isometric magnesium oxide was first found in ejected blocks of limestone on Monte Somma, Vesuvius. It was described by Scacchi in 1841 under the name periclasia. The English equivalent of this is periclase, but some American mineralogists insist upon calling the mineral periclasite. Periclase is simpler and more euphonious and should be retained. As Cole¹ has well said " . . . the terminology of minerals formerly possessed, for the founders of the science, as agreeable a variety as that of other branches of natural history. There seems no need to make technical language harsh by undue repetition of sounds that have no historic warrant."

Since its original discovery, periclase has been found at ten other localities.² While it is a comparatively rare mineral, it seems to be widely distributed.

* Paper presented at the ninth annual meeting of the *Mineralogical Society of America*, New York City, Dec. 28, 1928.

¹ *Outlines of Mineralogy*, G. A. J. Cole, p. 169, London, 1913.

² Teulada (Sardinia), León (Spain), Predazzo (Tyrol), Nordmarken, Långban, and Tenneberg (Sweden), Pulpit Rock and River Don (Tasmania), Bogoslawsk district (Urals), and Riverside (California).

DESCRIPTION OF THE CALCITE-BRUCITE ROCK OR PREDAZZITE.

I first found periclase at Crestmore in July, 1926, in what is known as the "Wet Weather" Quarry. It occurs in a calcite-brucite rock or predazzite. The predazzite is a white medium-grained crystalline (metamorphic) limestone with disseminated spots of a light gray mineral which proves to be brucite by chemical and blow-pipe tests.

The brucite spots are equant and vary in size from 1 to 3 mm. A thin section of the predazzite is shown in Fig. 1. For comparison a photomicrograph of predazzite from Fassathal, the type locality for predazzite, is shown (Fig. 2). Here the brucite spots are smaller, but more regularly distributed. It is no wonder that predazzite was described as a mineral by Petzholdt in 1843 when it is recalled that thin sections were not used at that time.

The brucite occurs not only in the definite areas described and figured (Fig. 1), but also in minute veinlets between these areas. Some of these veinlets definitely replace calcite.

The Crestmore brucite has a complicated scaly-concentric structure which is well brought out in Fig. 3. I say scaly-concentric rather than fibro-concentric structure since the elongation of the units is parallel to the faster ray and hence we have sections of basal plates and not fibers. (The optical character of brucite is positive).

The brucite shows anomalous interference colors; a peculiar reddish-brown hue takes the place of orange and red of the first order and first-order yellow is lacking. If the section is too thin the anomalous interference colors are not present.

CHONDRODITE. In addition to the brucite, the predazzite contains numerous small (0.03 to 0.35 mm.) colorless crystals of chondrodite. These are much rounded crystals, somewhat tabular parallel to $\{010\}$. Fig. 4 is a photomicrograph of some of the chondrodite grains which were isolated by dissolving the predazzite in very dilute hydrochloric acid. The rounded character is not due to solution in the acid, for the mineral grains in thin section also show a rounded outline. Many of the chondrodite crystals are twinned on $\{001\}$ and are usually made up of 2, 3, 4, or 5 individuals, rarely more. Fig. 5 is a camera lucida drawing of a few of these twinned crystals of chondrodite. The chondrodite is identified by the indices of refraction ($n_\gamma = 1.635$, $n_\alpha = 1.605$, determined by the immersion method) and by the maximum extinction angle of 26° in twinned

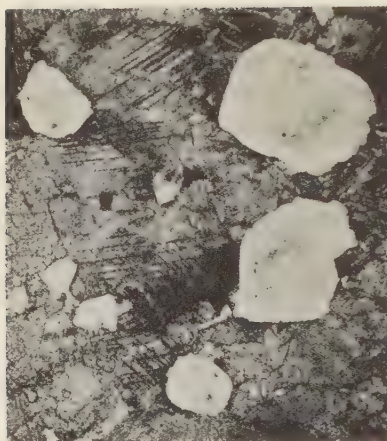


FIG. 1. (X18 diameters). Thin section of predazzite from Crestmore, California. Light areas = brucite



FIG. 2. (X30). Thin section of predazzite from Fassathal, Tyrol. Light areas = brucite.



FIG. 3. (X100). Thin section of brucite showing scaly-concentric structure. (crossed nicols) Crestmore, California.

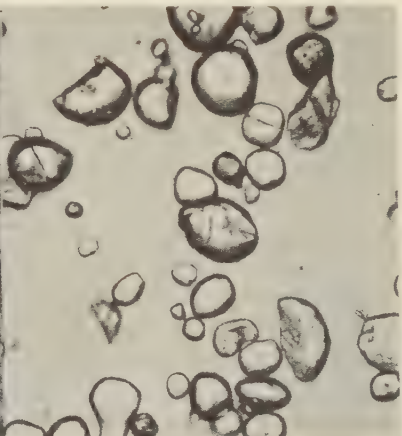


FIG. 4. (X60). Chondrodite crystals isolated from predazzite. The dark fragment in the upper right-hand corner is spinel. Crestmore, California.

crystals, where the trace of the twin-plane $\{001\}$ is used as a reference line.

WILKEITE. Some thin sections of the predazzite contain a number of subhedral prismatic crystals of wilkeite. They vary in size from 0.3 mm. to 1.2 mm. In the hand specimen they are visible with a lens as minute, colorless, subhedral crystals. Ordinarily these crystals would be called apatite, for they show low first-order colors, elongation parallel to the faster ray, and rather high relief. The

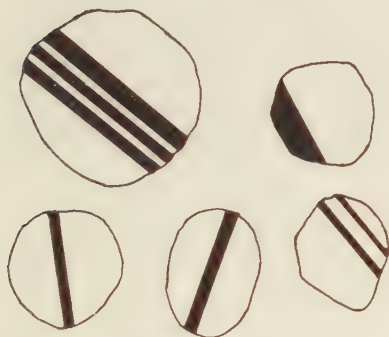


FIG. 5. (X90). Twin-crystals of chondrodite. $\{001\}$ = twin-plane.

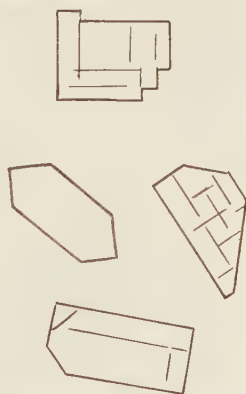


FIG. 8. (X40). Cleavage fragments of periclase.

nitric acid solution of the predazzite gives a wet test for the phosphate radical, and with 50% ethyl alcohol, microchemical gypsum is deposited from the nitric acid solution on cooling. Isolated fragments of the mineral also give the same tests. Only minerals containing calcium sulfate (which are anhydrite, bassanite, gypsum, polyhalite, thaumasite, glauberite, syngenite, haüyne, scapolite, and wilkeite) give microchemical gypsum from acid solutions. This is proof that the mineral is wilkeite and not apatite. This is confirmed by an index of refraction determination of 1.650.³ The original wilkeite was found in a blue crystalline limestone with another rock type (predazzite).⁴

³ The index of refraction for wilkeite (1.640 ± 005) given by Eakle and Rogers (*Ref. 1*, p. 264) is too low. The value should be $n_a = 1.650$; $n_\gamma = 1.655$. (Det. by the writer).

⁴ The calcite-brucite rock described by the writer in his 1918 paper (4) contains wilkeite and not apatite as reported. To make the test, dissolve some of the rock in dilute nitric acid, add 50% ethyl alcohol, and then drop in another fragment of the rock. The solubility is diminished and gypsum is precipitated.

SPINEL. The predazzite also contains a few minute (about 0.1 mm.) olive-green isotropic grains of spinel. (See Fig. 4).

HYDROMAGNESITE. On and near the surface of some of the blocks of predazzite, the brucite is altered to a white, nearly opaque mineral which is identified as hydromagnesite.

The predazzite from the "Wet Weather" Quarry is similar to the one from the Chino Hill quarry described by Eakle (3) and Rogers (4), except that the brucite aggregates are smaller. No periclase was ever found in the Chino Hill specimens though Eakle (3) came to the conclusion that the brucite had been formed from periclase.

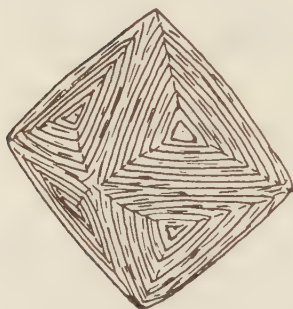


FIG. 9. (X30). Form of the original periclase crystals, now converted into brucite.

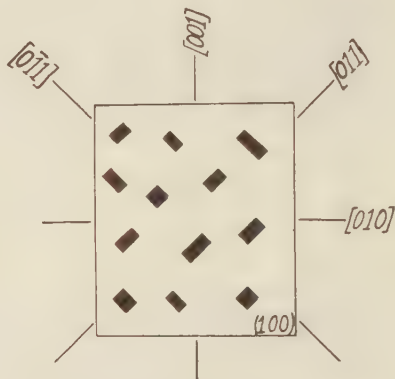


FIG. 12. (X15). Inclusions of magnetite in periclase.

DESCRIPTION OF THE PERICLASE.

The periclase is found as cores within some of the brucite aggregates, as shown in Fig. 6. The mineral is pale gray to almost colorless with a subadamantine luster and reaches a maximum size of about a millimeter. The mineral is similar to the Riverside periclase described by the writer (4) a decade ago. Crushed fragments of the periclase are clear and colorless, with a square or rectangular outline as shown in Fig. 8. They have a perfect cubical cleavage and a dodecahedral parting. They are dark between crossed nicols and have an index of refraction slightly greater than 1.74. The fragments are soluble in hot dilute hydrochloric acid and give a microchemical test (struvite) for magnesium with NH_4OH and Na_2HPO_4 .

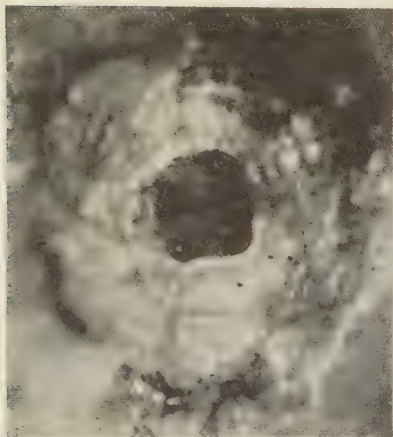


FIG. 6. (X16). Hand specimen. Periclase core surrounded by concentric layers of brucite. Crestmore, California.

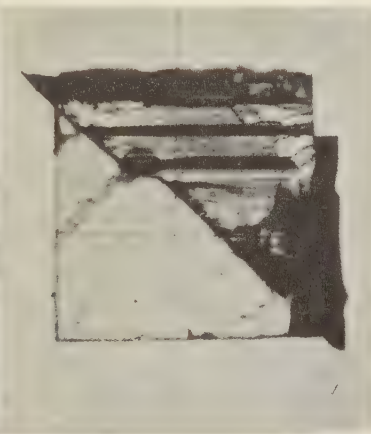


FIG. 7. (X12). Artificial periclase, showing cubic cleavage and dodecahedral parting. If the plate is taken parallel to (001), the horizontal lines represent parting parallel to (101).

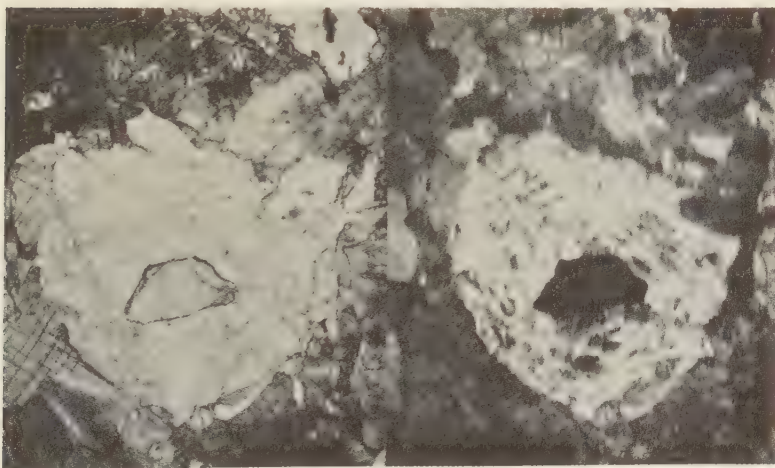


FIG. 10 (X25). Thin section of predaz-zite showing core of periclase in brucite aggregate. Crestmore, California.

FIG. 11. (X25). The same as Fig. 10, but taken with crossed nicols.

Some of the periclase contain minute (0.007 to .02 mm.) black opaque inclusions of magnetite. With high magnification they are square or rectangular in outline, with the orientation shown in Fig. 12. These crystals are either octahedrons or dodecahedrons depending upon whether faces are developed in the diagonal zones $[011]$ and $[0\bar{1}1]$ or in the axial zones $[010]$ and $[001]$. A careful examination, with reflected light thrown on the microscope stage from above, proves that faces are present in the diagonal zones and so the magnetite crystals are octahedrons.

As can be seen from Figs. 10 and 11, the brucite is clearly an alteration product of periclase and the periclase is a relict mineral from an earlier stage. Only a few periclase cores can be found within the brucite aggregates of the specimens collected. Out of about 100 brucite spots in ten thin sections only two contained any visible periclase. According to a rough statistical estimate made graphically, 100 brucite spots with periclase centers of the relative size of Fig. 10 should contain about 16 cores. This is practically proof that the alteration was in most cases virtually complete. This is one reason why periclase is such a rare mineral. The alteration of periclase to brucite is doubtless brought about by hydrothermal solutions at a stage a little later than the main period of metamorphism, which was essentially dedolomitization.

The original form of the periclase is well preserved in the brucite pseudomorphs. The crystals were similar to Fig. 9, that is to say, oscillatory combinations of the octahedron and dodecahedron with a slight development of the trisoctahedron. They very much resemble some diamond crystals.

NOTE ON ARTIFICIAL PERICLASE

Artificial periclase is better known than the natural mineral. It has been prepared by many investigators.⁴ Fig. 7 is a photomicrograph of a cleavage fragment from a large (5 cm.) clear colorless cleavage block of artificial periclase, which was kindly lent to me by Mr. C. E. Hesthal, my colleague of the physics department. It shows dodecahedral parting as well as cubic cleavage.

Artificial periclase is now made on a commercial scale by the Vitrefrax Corporation of Huntington Park, near Los Angeles, California. It is produced from carefully selected magnesite in electri-

⁴ For references see Hintze's *Handbuch der Mineralogie*, Vol. 1, 2d abth., p. 1888, 1915.

cal furnaces and is sold under the trade name "Sierra Periclase." It is said to be the most perfect electrical insulator known, but is too expensive to be used for many purposes. I am indebted to Dr. T. S. Curtis, research director of the Vitrefrax Corporation, for specimens of artificial periclase produced at their plant.

LIST OF MINERALS FOUND AT CRESTMORE, NEAR RIVERSIDE, CALIFORNIA

(The numbers refer to the papers listed in the bibliography).

Graphite, 3	Malachite, 3	Phehnite, 3
Galena, 3	Azurite, 3	Chondrodite, 4
Sphalerite, 3	Hydromagnesite, 3, 4	Tourmaline, 3
Xanthochroite, 3	Anglesite, 3	Okenite, 3
Pyrrhotite, 4	Apatite, 3	Apophyllite, 3
Pyrite, 3	*Wilkeite, 1, this paper	Centrallassite, 9
Arsenopyrite, 3	Orthoclase, 3	Laumontite, 3
Chalcopyrite, 3	Microcline, 3	Biotite, 3
Bornite, 3	Oligoclase, 3	Phlogopite, 3
Tetrahedrite, 3	Labradorite, 3	Xanthophyllite, 2
Quartz, 3	Diopside, 3	Clinocllore, 3
Chalcedony, 7	Augite, 3	Deweylite, 4
Periclase, this paper	Wollastonite, 3	Thaumasite, 5
Opal, 3	Grossularite, 3	Titanite, 3
Hematite, 3	Monticellite, 2	*Crestmoreite, 3
Limonite, 3	Scapolite, 3	*Riversideite, 3
Brucite, 3, 4	Gehlenite, 8	*Merwinite, 8
Magnetite, 4	Vesuvianite, 3	*Jurupaite, 7
Spinel, 4	Zircon, 3	Custerite, 12
Calcite, 1	Datolite, 3	Spurrite, 5
Aragonite, 3	Epidote, 3	*Plazolite, 6
Cerussite, 3	Axinite, 3	*Foshagite, 10

* The starred minerals were new minerals when described.

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| (2) Eakle, A. S., <i>Jour. Wash. Acad. Sci.</i> , vol. 6, pp. 332-335, 1916. | (5) Foshag, W. F., <i>Am. Mineralogist</i> , vol. 5, pp. 80-81, 1920. | (9) Foshag, W. F., <i>ibid.</i> , vol. 9, pp. 88-90, 1924. |
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| | (8) Larsen, E. S. and Foshag, W. F., <i>ibid.</i> , vol. 6, pp. 143-148, | (12) Tilley, C. E., <i>Geol. Mag.</i> , vol. 65, pp. 371-372, 1928. |

STRUCTURES OF SULFIDES AND SULFOSALTS

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INTRODUCTION

Mineralogists who look forward to simple and definite chemical formulas of minerals based on a knowledge of their structures will see their expectations only partly fulfilled. It is now well known that probably only organic crystals (including solid CO_2 and NH_3) possess definite molecules, while in inorganic solids the molecule as such does not seem to exist. A few possible exceptions may include very complex compounds like the micas (1). The sulfides and sulfosalts whose structures have been determined do not show definite combinations of atoms that could be designated as molecules. Some seem to contain distinguishable radicals, however, if S_2 in pyrite, for example, may be considered a radical.

In the following pages the different types of sulfides and sulfosalts including several artificial compounds will be discussed and interesting similarities will be pointed out. Many tellurides and selenides have the same structures as the corresponding sulfides but they will not be mentioned here. Whether the particles composing the structures are in the atomic or ionic state is still doubtful. Reference to this subject will be made only in two or three groups enumerated. It is impossible to give all the references to the original investigations of the structures described. Ewald's and Herrmann's volume "Strukturbericht" (2) contains most of these, and frequent reference will be made to this compilation.

SULFIDES

NaCl STRUCTURE TYPE: Galena, PbS , MgS , CaS , SrS , BaS and alabandite, MnS , crystallize like NaCl (2, p. 72), see Fig. 5 in this journal,¹ page 183. If we imagine the S atoms to be connected which are nearest to one another we notice that each group of four forms a regular tetrahedron. A whole net work of tetrahedrons is obtained in this way. These S atoms have the so-called cannon ball arrangement designated by W. H. and W. L. Bragg as face-centered cubic close packing (3, p. 161). Spheres of equal radius which touch when arranged in this manner occupy the smallest possible space. It seems to be a very common packing of oxygen in oxides and silicates according to Bragg and other investiga-

¹ In order to avoid repetition of drawings, reference will be made to the figures in the paper "Crystal structure types," this journal, vol. 14, pp. 182-187, 1929.

tors. In the structures under discussion the S atoms cannot touch one another because the metal atoms are also arranged in the same pattern and their tetrahedrons interpenetrate the S tetrahedrons. It depends on the size of the metal atom as to how close the S atoms can approach each other. The length of the edge of the S tetrahedron in PbS, for example, is 4.19\AA while in MnS it is 3.68\AA . If we compare the measured dimensions of the unit cells of these sulfides with those computed from the atomic and ionic radii of Goldschmidt (4) we find that the ionic ones are in better agreement than the atomic ones. Whether this means that the particles are ions (making the lattices polar) or not, is not apparent, for in all the remaining structures discussed below the *atomic* radii agree better, or just as well, as the ionic radii with the measured dimensions.

A noteworthy feature is that the natural minerals crystallizing with NaCl structure, NaCl, PbS, MnS, MgO, PbSe, PbTe, MnO, have cubic cleavage. Exceptions are AgCl, AgBr and AgI which have no cleavage at all.

ZINCBLENDE STRUCTURE TYPE: BeS, zincblende, ZnS, (including the iron rich marmatite and christophite), artificial CdS, and black HgS crystallize in this type (2, p. 76). To illustrate this type see this journal, vol. 14, p. 185, Fig. 8. The S atoms as well as the metal atoms form regular tetrahedrons in such a way that one half of the tetrahedrons of one element have an atom of opposite charge in their centers. The radius of the metal atom in the center of the S tetrahedron determines its size. Since the S atoms as well as the metal atoms, viewed independently, form face-centered cubes they have the same close packing arrangement observed in NaCl structures. As was pointed out by Goldschmidt (4, p. 75) the atomic radii when used to compute the theoretical dimensions of the zincblende structure agree much better with the measured values than the ionic ones, a fact which has led some investigators to believe that this lattice may be an atomic (non-polar or homoeopolar) one.

WURTZITE STRUCTURE TYPE: Only two sulfides, wurtzite, MnS, and greenockite, CdS, belong to this hexagonal type. A diagram of this structure is shown in this journal, vol. 14, p. 185, Fig. 9. It resembles zincblende in the following respects:

1. The distances between the atoms are practically identical to those in zincblende.
2. A rotation of 60 degrees of *alternate pairs* of (0001) atomic layers about the three fold axis produces the zincblende structure.

3. The S as well as the metal atoms form interlocking tetrahedrons. Since the axial ratio c/a in wurtzite is almost exactly 1.633 (which is twice the ratio of the height of a regular tetrahedron to its edge) the tetrahedrons are practically regular. The same is true of CdS.

4. The arrangement of the S as well as the metal atoms—each one viewed independently—is that of hexagonal close packing. This as pointed out by Bragg (3, p. 161) is the alternative of close packing and produces just as dense a structure as the face-centered cubic packing, provided the hexagonal axial ratio c/a is 1.633.

NIAS STRUCTURE TYPE: Pyrrhotite, FeS, artificial NiS (not millerite), and CoS belong to this hexagonal type (2, p. 84). See this journal, vol. 14, p. 183, Fig. 6. Only the S atoms have the positions of hexagonal close-packing as discussed for wurtzite. However since the axial ratios c/a are 1.688, 1.55 and 1.52, respectively, the packing is not as close. Again the S atoms form almost regular tetrahedrons which, however, do not contain any metal atoms. Each metal atom is surrounded by 6 S atoms which are at the corners of a slightly distorted octahedron.

No structural reason for the easy replacement of Fe by S in pyrrhotite can be given, unless it is the tendency for the S atoms to form radicals similar to S-S, as found in pyrite. In pyrrhotite replacement of Fe by S would bring certain S atoms as close together as 2.45\AA , while in the theoretical pyrrhotite structure the S atoms are separated by at least 3.43\AA . The S atoms in the pyrite radical (See Fig. 1) are only 2.09\AA apart which is closer than in any other determined sulfide.

CINNABAR: Cinnabar, HgS, is hexagonal but it resembles a distorted NaCl structure (2, p. 88). Therefore, one may apply what has been said concerning PbS provided the distortion of the lattice is not left out of consideration.

FLUORITE STRUCTURE TYPE: The cubic chalcocite, Cu_2S , Na_2S , and Li_2S belong to this type (2, p. 148). A diagram of the structure is given in this journal, vol. 14, p. 185, Fig. 11. The S atoms occupy the Ca positions in fluorite while the metal atoms occupy those of F. For this reason Goldschmidt refers these structures to the "anti-fluorite" type. The S atoms are arranged in face-centered cubic close packing and form, therefore, regular tetrahedrons. Each tetrahedron contains one metal atom. The metal atoms are arranged in small cubes.

PYRITE STRUCTURE TYPE: Pyrite, FeS_2 , hauerite, MnS_2 , CoS_2 , and NiS_2 crystallize in this type (2, p. 150). Cobaltite, CoAsS , gersdorffite, NiAsS , and ullmannite, NiSbS , have very similar structures. One of the S atoms of the S-S radical might be considered as being replaced by As or Sb. In pyrite the metal atoms have face-centered cubic arrangement as shown in Fig. 1. Each metal

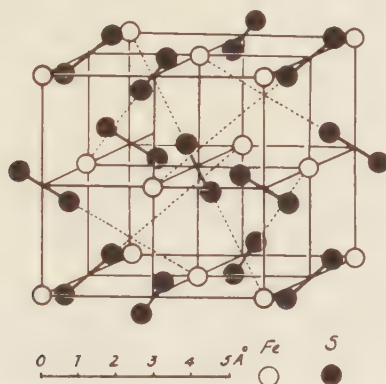
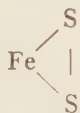


FIG. 1. Unit cube of pyrites. The dotted lines are threefold axes of symmetry.

atom is surrounded by a somewhat distorted inclined octahedron of six S atoms. The arrangement is similar to pyrrhotite in that respect. In pyrite we encounter a S-S radical and therefore Niggli writes the formula as:



The two S atoms of the radical are only 2.09 Å apart. The radicals might be compared to dumb-bells whose axes are parallel to the threefold cubic axes. The radicals are distributed in such a manner that each octant of the unit cube contains half a radical. But the axes of adjoining radicals (which are less than the length of the edge of the unit cube apart) are not parallel as may be seen in Fig. 1. Each S atom of the radical forms the corner of three tetrahedrons which are symmetrical with respect to the threefold axis in which the radical lies. These slightly distorted tetrahedrons are linked to other sets of tetrahedrons directly, as well as by means of the radicals. It is not feasible to show this arrangement in a two dimensional diagram. The centers of gravity of the "dumb-bells"

are in the positions of face-centered cubes, and, therefore, the *radicals* are in close packing. This gives a very dense structure for pyrite as seen by a comparison with zincblende whose unit cell has practically the same size. Each cell contains four molecules but pyrite has twice as many S atoms in the same volume.

MOLYBDENITE STRUCTURE TYPE: Molybdenite, MoS_2 , WS_2 and probably TiS_2 (9) crystallize in the hexagonal layer lattice type (2, p. 164). See this journal, vol. 14, p. 187, Fig. 17. These structures seem to be the result of the great deforming influence of tetravalent metal atoms (5, p. 180). The metal atoms are arranged in layers parallel to the base. Sets of two equivalent layers of S atoms are placed between the metal layers. The S atoms form layers of trigonal pyramids which are 3.66\AA (3.63\AA in WS_2) in length along the pyramid edges and 3.15\AA (3.18\AA in WS_2) along the basal edges. One is tempted to compare these pyramids with somewhat stretched tetrahedrons the elongation being due to the deforming influence of the metal atoms. The good basal cleavage in these compounds shows that the bonds between the S layers are relatively weak.

SULFOSALTS

There seems to be no general agreement among chemists and mineralogists as to what constitutes a sulfosalt. Some restrict the term to salts of hypothetical sulfoacids of V, As, Sb, and Bi. Others include sulfoferrites, as for example chalcopyrite and bornite. The writer believes the latter course the more logical one. Structurally there is little if any evidence that, for example, tetrahedrite resembles more closely a sulfosalt than does chalcopyrite. As a matter of fact they are surprisingly similar as will be shown later. Distinct radicals are no more frequent (as far as we know now) among the sulfosalts than among the sulfides. It will be shown, however, that those minerals which are classed as sulfosalts by the writer have at least two positions which are not equivalent structurally for the two or more metals. The Fe atoms in chalcopyrite, for example do not occupy interchangeable positions with Cu. Or in linnaeite $(\text{Co}, \text{Ni})_3\text{S}_4$ the Co and Ni positions are structurally not the same or equivalent. The formula should be written CoNi_2S_4 or NiCo_2S_4 . In this case, as in most sulfosalts, isomorphous replacement is a prominent feature and a Co atom may take the place of a Ni atom or vice versa. But if it does, the new position which the Co fills remains a Ni position structurally.

The writer would suggest, therefore, that *a salt in order to be considered a sulfosalt must have at least two structurally non-equivalent positions for its two or more metals.*

CHALCOPYRITE: The structure of chalcopryrite, CuFeS_2 , is represented by Fig. 10, this journal, vol. 14, p. 185. The arrangement of the S atoms in tetrahedral close-packed fashion is very similar to that in zincblende. As a matter of fact the structure as a whole (2, p. 279) is like zincblende if we disregard its tetragonal character, which is due to the fact that only alternate metal layers that are parallel to the base consist of the same metal, and

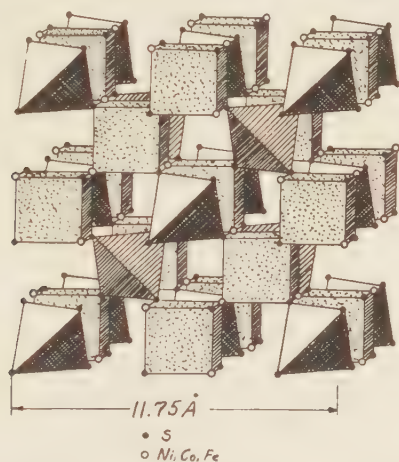


FIG. 2. Arrangement of tetrahedrons in linnæite (magnetite type). Each small cube also consists of a S tetrahedron and an interpenetrating metal. Each tetrahedron (not those in the cubes) contains a metal atom at its center. The eight atoms in the centers of the tetrahedrons at the corners of the drawing are the corners of a unit cube of linnæite. (After Ewald and Hermann.)

that the Fe positions are structurally not equivalent to the Cu positions.

STANNITE: Stannite, $\text{Cu}_2\text{SnFeS}_4$, is very closely related to chalcopryrite (2, p. 291). Though the S positions have not been determined with certainty it may be predicted that they resemble those of chalcopryrite. The three metals occupy positions which are not equivalent.

MAGNETITE STRUCTURE TYPE: Linnæite, $(\text{Co}, \text{Ni})_3\text{S}_4$, polydymite, $(\text{Ni}, \text{Fe}, \text{Co})_4\text{S}_5$, and sychnodymite, $(\text{Co}, \text{Cu}, \text{Ni})_4\text{S}_5$, crystallize in this type (8). Fig. 2 is a diagram of the structure. The 32 S

atoms (occupying the O positions of magnetite) form a tetrahedral net work of face-centered close-packed particles. Since the metals Co, Ni, Fe and Cu are very similar in radius and mass it is not known which metals occupy the 16 positions corresponding to ferric iron in magnetite and which the 8 ferrous positions. There is also considerable isomorphous replacement.

It will be noticed that the ratio of metal to S is 4:5 in polydymite and synchondymite. This is not such a serious objection, however. Translated into atoms of the unit cell it means 25.6:32, instead of 24 of the metal to 32 of S. This discrepancy might be explained in several ways. Submicroscopic impurities could be responsible. It is also conceivable that a metal atom takes the place of a S atom which would be the reverse of what happens in

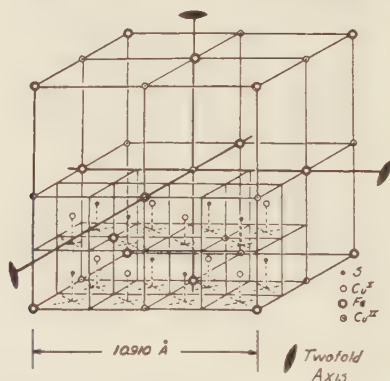


FIG. 3. Unit cube of bornite. The vacant octants may be filled by rotations about the twofold axes. (After DeJong.)

pyrrhotite. It has also been suggested that atoms may enter a structure without any definite positions of symmetry. This explanation is I believe too vague and should not be used till proof can be produced.

BORNITE: DeJong (6) has determined the structure of bornite. Its theoretical formula is Cu_5FeS_4 . Of the 40 Cu atoms (or ions) in the unit cell, Fig. 3, 32 are cuprous and 8 cupric. The 32 S atoms have the same arrangement as in linnaeite. Therefore, they are face-centered close-packed. The 32 Cu^{I} atoms are arranged in the same manner and their tetrahedrons bear the same relationship to those of the S atoms that a positive tetrahedron does to a negative one. A small discrepancy of less than 3 per cent of the parameter

of the Cu^{I} atom may be disregarded in this discussion. The structure of these 64 atoms closely resembles that of PbS (NaCl type). The eight Cu^{II} and eight Fe^{II} atoms are placed in the centers of some of the tetrahedrons of S and Cu^{I} . To account for the variable composition of bornite, from $\text{Cu}_6\text{Fe}_2\text{S}_6$ to $\text{Cu}_{18}\text{Fe}_2\text{S}_{12}$, it is only necessary to imagine an isomorphous replacement of Fe^{II} by Cu^{II} atoms or vice versa. These two types of atoms have very similar positions, comparable in that respect to positive and negative tetrahedrons. Partial replacement, therefore, should be common.

PENTLANDITE: This mineral $(\text{Fe}, \text{Ni})\text{S}$ has been considered a sulfide but its structure (7) suggests a sulfosalt to the writer. Its formula should be written $(\text{Ni}, \text{Fe})_3\text{FeS}_4$. Theoretically it is Ni_3FeS_4 . The S atoms are crowded into clusters of eight each. See Fig. 4. These eight form the corners of a small cube with an edge

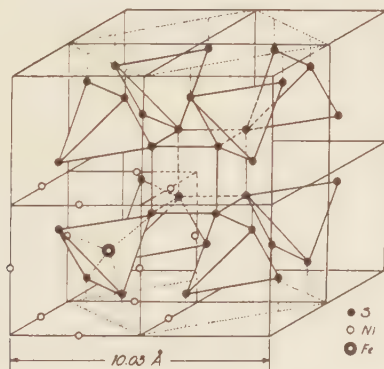


FIG. 4. Unit cube of pentlandite. Since the positions of the metal atoms are the same in all octants they have been shown in only one.

2.50 Å in length. This arrangement causes 8 S atoms to occupy a smaller volume than in any other mineral combination known. These cubes of S are linked in such a manner that the corners of each four adjoining cubes form tetrahedrons of S. Each tetrahedron contains an Fe atom at its center. This Fe atom together with three Ni atoms (which by themselves form an equilateral triangle) are arranged in tetrahedral fashion. A unit cube of this structure contains 24 Ni, 8 Fe and 32 S positions. Due to the peculiar distribution of the S atoms there appear to be "holes" in the structure.

SULVANITE: Sulvanite Cu_3VS_4 is supposed to belong to the enargite group. DeJong who recently published its structure (10) places it in the cubic system. The S atoms in the structure are identical in arrangement to those of pentlandite (Fig. 4) and show, therefore, the same crowding. The V atoms have the same positions as the Fe in pentlandite. The Cu atoms surround each V atom in the form of an octahedron as shown in Fig. 5.

TETRAHEDRITE: The structure of this much discussed mineral is now known. DeJong (6) used the formula $(\text{Cu}, \text{Ag})_3\text{SbS}_4$ in attempting to determine the structure, but Machatschki (11) has shown that this formula and structure are not in agreement with

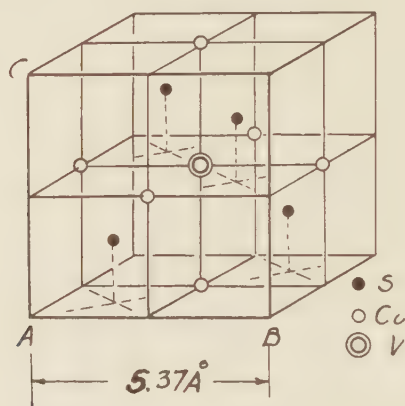


FIG. 5. An octant of a unit cube of sulvanite. All the faces of the octant are planes of symmetry. Reflection in them produces the other octants.

his own extensive investigation. The theoretical formula is $\text{R}_3^{\text{I}} \text{R}_4^{\text{III}} \text{S}_{13}$. R^{I} is chiefly Cu^{I} and Ag and R^{III} is Sb and As . A small excess of S is, however, very common which makes the working formula more often $(\text{R}^{\text{I}}, \text{R}^{\text{II}})_{12} \text{R}_4^{\text{III}} \text{S}_{13}$. There is no great difficulty in accommodating these extra S atoms in the structure.

The unit cell of tetrahedrite is very nearly eight times as large as that of chalcopyrite or sphalerite. One octant of the unit cube is shown in Fig. 6. The other octants result by rotation of the small cube about any of its edges as twofold axes. The structure resembles sphalerite or chalcopyrite, especially if the conventional point of origin O in Fig. 6 is shifted parallel to a threefold axis to the center A of the octant cube as pointed out by Machatschki (11). Then the 8 Sb positions lie almost at the corners of the resulting octant cubes

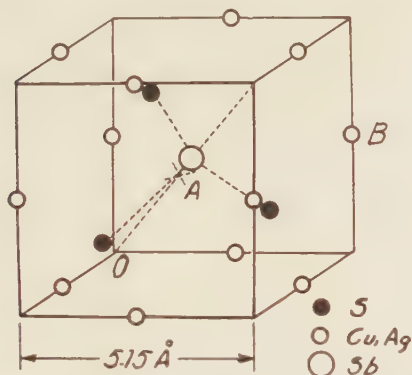


FIG. 6. An octant of a unit cube of tetrahedrite. The edges are twofold axes of symmetry. By their operation the other octants may be produced. The Sb atom is not in the center, A, of the octant but is displaced along the diagonal one eighth of the length of the diagonal of the octant.

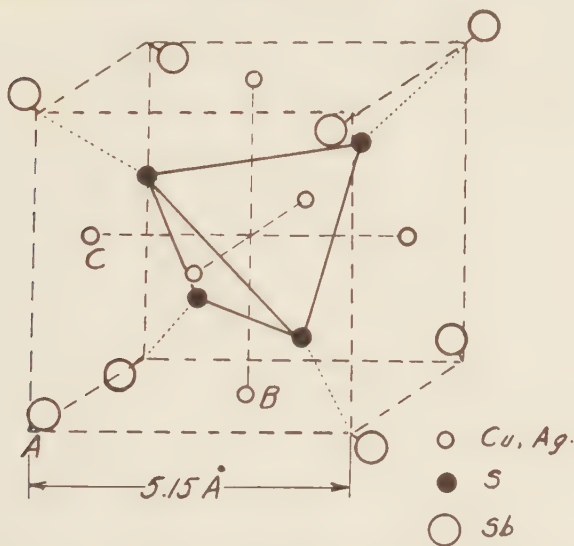


FIG. 7. Octant of tetrahedrite showing great similarity to the unit cell of chalcopyrite and sphalerite. A shift from O to A in Fig. 6 produces the octant shown. Corresponding atoms in the two figures are designated by the same letters.

as shown in Fig. 7 in which the positions corresponding to those in Fig. 6 have been designated by the same letters. Each octant cube has almost the same dimensions as the unit cell of chalcopyrite.

Also the arrangement of S and metal atoms is similar.

The metal atoms (including Sb) become face-centered for the octant cubes, and four S atoms, form tetrahedrons inside of the octant cubes (Fig. 7). But only six of the eight octant cubes contain these tetrahedrons. Two will be vacant, and it is in these that any excess S atoms over $R_3^{11}R^{11}S_3$ are probably found (11, p. 209). Divalent metals like Zn and Fe can probably take some of the positions of Cu and Ag provided these additional S atoms are present.

CONCLUSION

A comparison of the known structures of sulfides and sulfosalts shows the following important features.

1. Sulfosalts do not differ structurally from sulfides except the two or more metals in them occupy at least two structurally non-equivalent positions. This causes such minerals as pentlandite, for example, to come under the classification of sulfosalts.

2. Structural radicals are not distinguishable except in the pyrite group, pentlandite and sulvanite.

3. The most common arrangements of the S atoms in sulfides and sulfosalts seem to be those involving close packing of cubic face-centered (cannon ball fashion) and hexagonal types. It seems to the writer that slightly distorted close packing of this nature may also be expected in orthorhombic sulfides or sulfosalts. Oxygen atoms (or ions) also show these arrangements in many oxides and silicates as shown especially by W. L. Bragg.

4. With the exception of the layer lattices of the molybdenite group, most sulfides and sulfosalts have their S atoms arranged at the corners of regular or slightly distorted tetrahedrons. This necessarily follows in a close-packed structure. But S tetrahedrons also prevail in the other structures. The size of these tetrahedrons is determined by the radii of the metal atoms which are associated with them. The shortest tetrahedral edge seems to be in pyrite (3.09 Å), while in Na_2S the large radius of Na increases the length of the edge to 4.62 Å.

Though it is probable that future investigations may necessitate revisions of these conclusions it is hoped that the present non-mathematical comparative study will aid mineralogists in visualizing some of the combinations of structural units discovered in this large group of minerals.

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A SET OF THIRTY IMMERSION MEDIA

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During the course of some experiments recently completed it was necessary to measure the optical constants of a very large number of liquids and to study many more whose constants are given in tables of critical data. Having on hand then a considerable amount of data and material, it was deemed worth while to select a set of immersion liquids which might serve the petrographer better than those commonly used today.

Objections to standard immersion media are many and well known. Probably one of the greatest drawbacks is the extent to which these media change in index even over a short period of time. Essential oils commonly used such as cedar oil, clove oil and others are natural mixtures from which the lighter constituents evaporate, leaving a gummy residue. Others in standard sets are manufactured mixtures which change index even more rapidly. Such liquids when purchased are correctly marked in index to a round figure. However, the sets used by nearly all petrographers have corrected figures of successive dates on the bottles, and these are not in convenient round figures. Consequently it is almost essential to measure each liquid on the refractometer each time it is used.

Since the index of any liquid depends upon the temperature, it becomes necessary to work at a uniform temperature or to know what the temperature is. The difference in indices of commonly used liquids ranges for a degree centigrade from 0.0003–0.0007. These constants are given for the liquids listed below.

The liquids listed in the table are so far as possible single compounds. Evaporation does not, therefore, change the index. For the liquids of higher index it is necessary to use mixtures since liquids of high index are rare. The mixtures chosen are made of very similar liquids whose boiling points are close together. Evaporation therefore takes place in both liquids of the mixture at almost the same rate of speed. The change in index in these liquids due to this cause is slight, and seems to be at a minimum. They will be replaced by single compounds if suitable ones are found. There seems, however, to be little hope of finding suitable liquids of higher index and constant boiling point.

None of the liquids have indices which are represented by round figures nor is the interval between each pair of liquids exactly .010. Nor is this true of standard sets after a short period of time. The greatest interval is .014 and the least .006. The advantages offered

by this set seem more than to offset these slight disadvantages.

The liquids¹ are listed in the following table together with their boiling points, indices at room temperature and temperature coefficients.

<i>Liquid</i>	<i>B.P. °C</i>	<i>mm.</i>	<i>N_D 24°C</i>	<i>Temp. Coeff.</i>	<i>Dark Container</i>
Trimethylene Chloride	119.5	735	1.446	.00045	
Cineol	53-54	8(Eastman)	1.456	.00041	
Hexahydrophenol	161.	740	1.466	.00044	
Decahydronaphthalene	88.5-90.5	38	1.477	.00040	
Isoamylphthalate	(Tech.)	Eastman	1.486	.00038	
Tetrachloroethane	143-144.4	740	1.492	.00051	
Pentachloroethane	158-160	740	1.501	.00048	
Trimethylene Bromide	165-167	Eastman	1.513	.00048	
Chlorobenzene	130.5-130.8	740	1.523	.00053	
Ethylene Bromide					
+Chlorobenzene			1.533	.00054	
o-Nitroluene	220-220.4	740	1.544	.00053	
Xylidine	114-118	27	1.557	.00050	X
o-Toluidine	87-88.5	17	1.570	.00047	X
Aniline	66.8-67.2	4.5	1.584	.00045	X
Bromoform	147.5	736	1.595	.00056	
Iodobenzene + Bromobenzene			1.603	.00054	X
"			1.613	.00054	X
Quinolin	117-121	16	1.622	.00049	X
α-Chloronaphthalene	128-132	20	1.633	.00044	
α-Bromonaphthalene + α-Chloronaphthalene			1.640	.00044	
"			1.650	.00044	
α-Bromonaphthalene + α-Iodonaphthalene			1.660	.00045	X
"			1.670	.00044	X
"			1.680	.00044	X
"			1.690	.00044	X
Methylene Iodide + Iodobenzene			1.700	.00060	X
"			1.710	.00063	X
"			1.720	.00066	X
"			1.730	.00068	X
Methylene Iodide	80	15	1.738	.00070	X

¹ All of these liquids can be obtained from the Eastman Kodak Co., Rochester N. Y., or in sets ready for use from Dr. C. W. Muehlberger, Service Memorial Institute, Madison, Wisconsin.

NOTES AND NEWS

MAGNET COVE, ARKANSAS, AND VICINITY

WILLIAM L. HALTOM, *Alabama Museum of Natural History*.

In the days of yesterday when the Red Men roamed the forests of Arkansas they found a happy hunting ground, the realization of their heart's desire. With the dawn of another era there has remained a veritable happy hunting ground, not for the Red Man but for the mineralogists and geologists.

For over a century Magnet Cove, Arkansas, has been visited by mineralogists and geologists who have come to seek out its treasures. Magnet Cove is located on Arkansas Highway No. 6, twelve miles east of Hot Springs. As the name implies, this is a locality in which there is a large amount of magnetic iron ore.

From the external appearance and general features of the cove many have believed this to be an ancient volcanic crater. More recently, however, the general



FIG. 1. View of cut just west of Cove Creek Bridge where the Alabama Museum secured many specimens including one weighing 400 lbs.

consensus of opinion is that it is formed of intrusive igneous rock. The surrounding area is of the Tertiary age.

There are a number of separate areas in this small cove which abound in beautiful specimens. Recently the Highway Department made a cut through a small hill and exposed some beautiful deposits. This cut is on the highway just west of the Cove Creek Bridge. Here was exposed some of the most beautiful eudyalite crystals, also aegirite, acmite, calcite, vesuvianite, thomsonite, biotite, dysanallyte and wavellite.

Figure 1 gives an idea of how this cut appears. The bulk of the rock exposed is calcite. In between the ledges of calcite is the igneous rock which contains the beautiful crystals. Vesuvianite crystals may be found in the loose soil. By being careful not to roll any boulders on the highway one may do considerable digging here, which will be most profitable. It might be well to state that many pass this up as containing no interesting specimens, as it is very unpromising on a casual examination.

Another choice collecting spot is a small knoll about 250 yards south west of the Cove Creek Bridge. Here is found dysanallyte, magnetite, pyrite, limonite pseudomorphous after pyrite and the rare rutile 8-lings. It is possible that at one time these crystals were embedded in the calcite, but were liberated by weathering and decomposition. These crystals are now found loose in the soil.

Going east on the highway one will pass an old church on the left side of the road about $\frac{1}{2}$ mile from Cove Creek Bridge. In front of this church there is a small

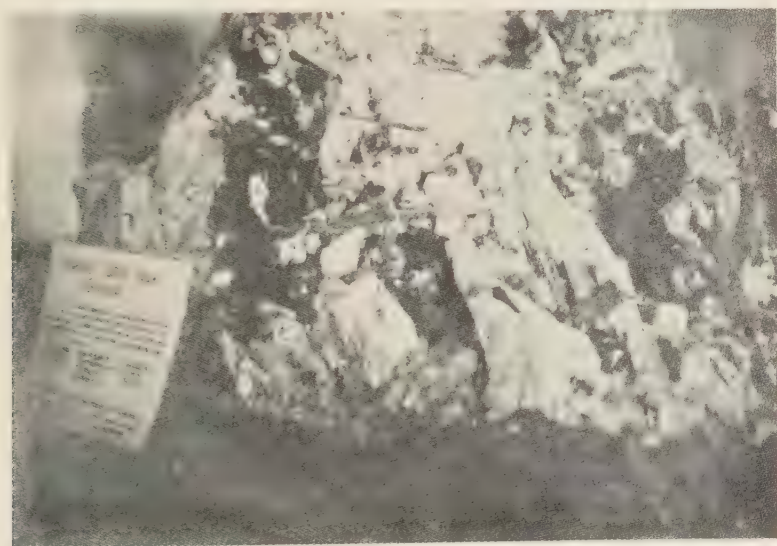


FIG. 2. View of case in Alabama Museum of Natural History. The specimen contains 10 minerals and weighs about 400 lbs. The black crystals are acmite, the white is feldspar.

creek, which is well worth examining. In this creek bed may be found small crystals of schorlomite, apatite, biotite, quartz and feldspar. These specimens are not numerous and are rather small, but are very handsome.

Schorlomite, named for its resemblance to schorl or black tourmaline, is found along the highway about $\frac{3}{4}$ mile east of Cove Creek Bridge. Here on top of a slight hill there is an old road which turns to the right, along this and in the surrounding fields excellent specimens may be found.

The highway cuts through several deposits of vermiculite, between Cove Creek Bridge and the eastern rim of the cove. Just which one of the vermiculites this is, I can not say. In the Proceedings of the Academy Natural Sciences of Philadelphia, 1877, page 277, Dr. G. A. Koenig calls this protovermiculite and gives an analysis comparing it with biotite from Mt. Vesuvius. Along with these deposits, in many instances, is a small amount of schorlomite but poorly crystallized.

One of the most cherished minerals found at Magnet Cove is brookite which is also referred to as arkansite. This mineral occurs in beautiful crystals on Quartz in a small area extending north and south from the Magnet postoffice, which is on the eastern rim of the crater.

From Magnet Cove the following minerals have been reported: acmite, aegirite, actinolite, augite, ankerite, allopahane, apatite, arkansite, biotite, braunite, chrysolite, calcite, dysanallyte, eudyalite, microcline, novaculite, nephelite, (eolite), ochre, monticellite, rutile, smoky quartz, schorlomite, tufa, vesuvianite, protovermiculite, variscite, phlogopite, wavellite, xanthophyllite, orthoclase, sodalite, astrophyllite, ilmenite, talc, pyrite, thomsonite, cancrinite, pyroxene, titanite, amphibole, wollastonite, natrolite, plagioclase, brucite, manganopectolite, diopside, melanite, leucite, pseudoleucite, olivine and perofskite.

A careful stroll over the entire cove will uncover many specimens, although it is impossible to find anything like all of these at present. It must be remembered that in nearly every collection in America and Europe there are specimens from this one locality which is only about a mile in diameter. Also the Alabama Museum has secured about 3 tons of choice specimens. At present good specimens of the following may be found: acmite, albite, apatite, arkansite, biotite, brookite, calcite, dysanallyte, eudyalite, feldspar, magnetite, microcline, novaculite, nephelite, ochre, monticellite, rutile, schorlomite, vesuvianite, xanthophyllite, illemitite, pyrite, pyrite altered to limonite, thomsonite and pseudoleucite.

Except at the cut just west of the Cove Creek Bridge no digging is necessary. An ordinary geological hammer is quite sufficient for the work, although a small shovel might come in handy. A hunter's compass is excellent for locating the larger magnetic iron ore deposits, however, a great deal of this ore which will cause a compass to deviate is still insufficient to pick up a needle or nail. A handy device to determine these specimens is a needle or nail attached to a thread. Instead of picking up countless worthless specimens, one may walk along and swing the needle against the specimens, and if highly magnetic it may be easily determined.

The entire cove is privately owned by a number of farmers, but the majority are very accommodating and will not object to trespassing unless the crops are needlessly destroyed. There is a good camp ground just to the right of the Highway on the west bank of Cove Creek. Excellent hotel accommodations may be had at Hot Springs.

Any one visiting this locality should also go to Crystal Mountain which is 18 miles west of Hot Springs on Highway No. 6, the same Highway Magnet Cove is located. Here some good specimens of quartz crystals may be secured.

By turning off of Highway No. 6 some distance west of Hot Springs as directed by signboards, one will come to Cedar Glades; continue on beyond this town to a small village about two miles farther. Here take the road to the right and go to Dug Hill, a familiar spot to the natives. At this locality may be secured beautiful green specimens of wavellite and variscite. It is necessary to dig in the old pits,

abandoned some 40 years ago and now almost hidden from view, in order to get these specimens.

About 60 miles west of Hot Springs, is Murfreesboro. Here is the famous Arkansas Diamond Mine. This mine is surrounded by a fence but visitors may be admitted. Good samples of green peridotite in which the diamonds are found, may be secured. If this trip to Murfreesboro is taken one will pass Glenwood. At this point a road leads to the right and about 6 miles from here is a large cut where specimens of dendritic manganese dioxide may be found. This is a pass through which Caddo River, the railroad and highway pass before reaching the village of Caddo Gap.

A CORRECTION. The ω index of the 5/6 sodium, 1/6 calcium artificial autunite, as given on page 268 (vol. 14, No. 7, 1929) should be 1.584. The value given, namely 1.605, is in error. The same correction applies to the table on page 274, where the first index given, namely 1.605, should read 1.584. Professor Winchell kindly called attention to the error.

Dr. Victor M. Goldschmidt, of Oslo, Norway, has been called to a professorship of mineralogy at the University of Göttingen.

Sir Stopford Brunton Bt. will be at Queen's University, Kingston, during the present session as research fellow in geology.

Dr. Ray S. Bassler has been appointed head curator of the department of geology of the U. S. National Museum to succeed the late Dr. George P. Merrill. Dr. Bassler has been connected with the division of paleontology of the Museum since 1901.

On the last pages of this Journal will be found a preliminary list of titles of papers to be presented before the Society at its annual meeting to be held in Washington, D. C., December 26-28, 1929.

Mr. Earl T. Apfel of Syracuse University has suggested the use of a quick-drying lacquer for marking specimens of minerals and rocks. The letters or figures are then written on the white or orange colored lacquer with drawing ink.

PROCEEDINGS OF SOCIETIES

Academy of Natural Sciences, Philadelphia, October 3, 1929.

A stated meeting of the *Philadelphia Mineralogical Society* was held on the above date, Mr. H. W. Trudell presided. There was an attendance of 56 members. The names of Messrs. Benjamin H. Shoemaker 3rd, and Alexander Fleming were proposed for membership. The following officers were elected for the coming year: President, Charles R. Toothaker; Vice President, Morrell G. Biernbaum; Secretary, Lester W. Strock; Treasurer, Wilfred Broadbelt; and Councilor, Charles R. Toothaker.

Mr. Strock addressed the Society on "MINERAL COLLECTING IN NOVA SCOTIA," based on a trip taken by the speaker and Mr. Biernbaum to that region,

last July. The general geology of the area was described with emphasis placed on the Triassic sediments and the typical igneous intrusions of that period. A model showing the peculiar conditions existing about the Bay of Fundy has been made and was explained in detail. The sixty foot tide cuts rapidly into the trap and sandstone frequently forming vertical cliffs, rising in some instances 400 feet from the water's edge. These cliffs are easily eroded and many zeolites are exposed, making collecting a far more simple matter than in most trap localities.

The route as described started at Yarmouth, continued along St. Mary's Bay, up the Annapolis valley to Wolfville, across Minas Basin to Parrsboro which became the base for all north shore localities. Exceptional stilbite and golden calcite were obtained at Partridge Island also fine quality chabazite at Wasson's Bluff. On Two Islands an interesting variety of white gmelinite was found which showed well developed prisms and upper and lower hexagonal pyramids, individual crystals occurring up to $\frac{3}{4}$ of an inch in length. Pinnacle Island yielded water-clear analcite and natrolite. The gmelinite veins on Pinnacle Rock, in the Five Islands group, were visited and from which Mr. Biernbaum secured a very superior specimen. Recrossing Minas Basin, Blomidon, Scotts Bay and Margaretville were visited, also the gypsum mines at Winsor along with many other less noted localities. The talk was illustrated by a number of colored slides which included a group showing the effects of the unusual tides.

Mr. Cinkowski exhibited several beautiful specimens of calcite and galenite from Joplin, Mo., also a number of geodes from Keokuk, Iowa. Mr. Arndt showed a splendid collection of New England minerals, including datolite from Westfield and garnets from Russell, Massachusetts; also manganite and diasporite. Mr. Oldach, in describing a summer trip in Texas and New Mexico told of seeing an area of some 200,000 acres, located in the Tularosa Valley, southwest of Alamogordo, N. M., covered with gypsum sand and which in certain areas was blown into immense dunes of intense whiteness. In many places throughout this area, shallow excavations would yield large, clear gypsum crystals. He also spoke of finding small gypsum crystals on the dumps at French Creek Mines, Pennsylvania, doubtless resulting from the reaction on limestone, of waters containing sulphuric acid derived from the alteration of iron sulphides. Mr. Biernbaum reported secondary gypsum crystals about the edges of ponds near the old gypsum dumps at Winsor, N. S.

LESTER W. STROCK, *Secretary*

BOOK REVIEWS

ELEMENTS OF MINERALOGY. FRANK RUTLEY. REVISED BY H. H. READ. 22nd edition. XXII + 394 pages. Thos. Murby & Co., London; D. Van Nostrand Co., New York. 1929. Price \$2.50.

This well known popular text has recently appeared in its twenty-second edition. The changes that have been introduced are largely of a minor nature. In an attempt to bring the book up-to-date more space has been allotted to the portion dealing with the production and uses of minerals of economic importance.

The use of a number of antiquated cuts, such as the ones illustrating the Jolly balance and the polarizing microscope, detract somewhat from the modern appear-

ance of the book. One finds also that the early conception of hemihedrism is still emphasized, namely, the development of these forms through suppression and expansion of faces of holohedral forms. The definition of a mineral and a rock might likewise be questioned in some quarters as in the former a *definite* chemical composition is made an absolute prerequisite while rocks are defined as mechanical mixtures of minerals.

The portion devoted to the occurrence and uses is, in the main, quite satisfactory although several omissions were noted. Texas is not mentioned as a sulphur producing State and no economic uses are indicated for andalusite.

W. F. H.

DANA'S MANUAL OF MINERALOGY. WILLIAM E. FORD. 14th edition. X+476 pages, 360 figures. John Wiley & Sons, Inc., *New York*. 1929. Price \$4.00.

Compared with the previous edition which was issued sixteen years ago the fourteenth edition follows the same general presentation and arrangement of subject matter. The pagination shows an increase of sixteen pages and a few new cuts have been added. Portions throughout the text have been rewritten and some new material has been added to those sections dealing with crystal structure, paragenesis, uses and occurrence of the minerals. The mineral statistics have likewise been revised.

While modern in many respects, unfortunately, quite a number of slips (and omissions) have been carried over from previous editions. Arsenic and mercury have been omitted from the table recording iodide films (p. 95); potassium is not included in the flame tests (pp. 98 and 99); the rubbed streak of molybdenite is not mentioned, nor the Meigen's test for aragonite; anorthosite is listed under the syenite group; while the weight of a carat is erroneously recorded as 205 instead of 200 milligrams. This new value for the carat was adopted in 1913.

W. F. H.

CORRECTIONS TO VOLUME 14

- No. 1, p. 37, 2nd line from bottom, for "Zinwald" read Zinnwald.
- No. 3, p. 84, 7th line, for "kind" read kinds.
 85, 7th line, for "Saeger" read Seger.
 88, 5th line from bottom, for "H." read F.
 101, 2nd line, for "devises" read devices.
 103, 19th line from bottom, for "between" read between.
 21st line from bottom, insert "is" after crystallization.
 105, 17th line, for "pegmatic" read pegmatitic.
- No. 6, p. 211, last formula in table, should be MgCO_3 .
 219, 16th line from bottom, for "silicate" read carbonate.
 227, first footnote line, for "Müggie" read Mügge and for "regelmäss-singen" read regelmässigen.
 234, 2nd line from bottom, for "dargestellen" read dargestellten.
 244, 15th line from bottom, for "dumotite" read dumontite.
- No. 7, p. 247, 3rd line from bottom for "winning" read twinning.
 249, 3rd line from bottom, for "diagonal" read diagonal.
 266, 10th line from bottom, for "soduim" read sodium.
 267, 2nd line from bottom, for "sixth" read sixths.
 268, 16th line for "1.605" read 1.584.
 269, 16th line from bottom, for "availabe" read available.
 274, 9th line, for "patassium" read potassium.
 22nd line, for "correllate" read correlate.
 274, 9th line from bottom for "1.605" read 1.584.
- No. 8, p. 286, 2nd line for "W.M." read H.W.
 300, last line before heading, for "other" read others.
- No. 9, p. 313, 7th line from bottom, for "Zirkil" read Zirkel.
 325, 2nd line above group 3, for "vesuvianite" read vesuvianite.
 340, 7th line, for "materia" read material.
 10th line from bottom, "niobuim" read niobium.
- No. 10, p. 344, 2nd line from bottom, for "chrombercynite" read chromhercynite.
 358, 2nd line from bottom, for "Larson" read Larsen.
 375, 1st line, the formula should read, toward the end, $6\text{SiO}_2 \cdot \text{H}_2\text{O}$.
 379, 4th line from bottom, for "lucoxene" read leucoxene.
- No. 11, p. 401, 7th line from bottom, in the last formula, for " Mg_8 " read Ca_8 .

INDEX TO VOLUME 14

PREPARED BY L. S. RAMSDELL

Leading articles are in **bold face type**; notes, abstracts and cross references are in ordinary type. Only minerals described in more or less detail are indexed. Titles of abstracted articles are not repeated when cross-indexed under author's names.

- Absorption spectra, mineral de-termination by. (Wherry)** 299, 323
 Åkermanite (melilite group) 404
 Algodonite 193
 Alling, H. L. [Review] 241
 Amelinite (new mineral in phonolite) (Marshall) 312
 Andalusite 378
 Anderson, O. Genesis of some types of feldspar from granitic pegmatites. [Review] 241
 Anhydrite 59
 Anhydrite-halite intergrowths. (Schaller) 106
 Anleitung zur chemischen Gesteinsanalyse. (Jakob) [Review] 76
 Apatite of igneous rock, inclusions in. (Groves, Mourant) 243
 Artificial gem stone, isomorphous with spinel. (Kerr) 259
 Atlas der letzten Linien der wichtigsten Elemente. (Löwe) [Review] 162
Atomic dimensions, new data on. (Wherry) 54
Autunites, artificial, base exchange in. (Fairchild) 265
 Bannister, F. A. Density and index of glasses applied to determination of imitation gems 243
 ——— 40, 387
 Barium-phlogopite. (Eckermann) 440
 Barrandite in Nevada. (Clinton) 434
Barth, T. Immersion melts of high refraction 358
Base exchange in artificial autunites. (Fairchild) 265
 Basic carbonate of Mn and Zn from Franklin, N. J. (Bauer, Berman) 103
Bauer, L. H., and Berman, 'H Loseyite, a new Franklin mineral 103, 150
 ——— **Moorite, a new mineral, and fluoborite from Sterling Hill, N. J.** 103, 165
 ——— New basic carbonate of Mn and Zn from Franklin, N. J. 103
Berman, H. Composition of the melilite group 389
 ——— **and Bauer, L. H. Loseyite, new Franklin mineral** 150
 ——— **Moorite and fluoborite** 103, 165
 ——— New Basic carbonate of Mn and Zn 103
 Bernal, J. D. 40
 Beziehungen zwischen Lichtbrechung, Dichte und chemischer Zusammensetzung in der Granatgruppe. (Phillipsborn) [Review] 241
 Bialite. (Buttgenbach) 439
 Bismutotalantite (Wayland, Spencer) 312
 Black Hills, mineral wealth. [Review] 437
 Bodenbenderite. (Rimann) 388
 Bonine, C. A. An unusual college monument 200
 Bonshtedt, E. M. 440
 Boracite, structure of. (Gruner) 102
 Bramlette, M. N. Natural etching of detrital garnet 336
 Bridgman, P. W. [Book Review] 386
 Brookite (arkansite), space group of. (Bernal, Martin) 40
 Brown, L. S. Appearance of tourmaline in sediments 104, 238

Buckley, H. E. Crystallization of potash-alum.....	244	Cooperite. (Cooper).....	339
—— Crystallography of some organic compounds.....	164	Coordinate angles, two circle and three circle. (Peacock).....	332
Buerger, M. J. and Huntsinger, H. A. A broad source of monochromatic light.....	329	Copper arsenides.....	188
Burt, F. A. Capsular silica.....	222	Copper crystals, new form.....	310
—— Soil Mineralogy. [Review]	163	Copper erratic, Illinois. (Crook).....	104, 119
Buszite. (Steinwachs).....	438	Copper pitch ore. (Guild).....	313
Buttgenbach, H.....	439	Cordierite-sillimanite gneisses.....	243
Calc-gneisses.....	243	Covellite, New Jersey.....	106
Calcium chloride, hydrophilite..	160	Cox, E. P. and Gabriel, A. Staining method for determination of minerals.....	290
Calcium sulphate, crystal forms of. (Ramsdell, Partridge)....	59	Crestmore, Calif., minerals, list of. (Rogers).....	469
Camsellite and szaibelyite. (Winchell).....	48	Crook, A. R. An Illinois record copper erratic.....	104, 119
Cananea, Mexico, ore body at. (Valentine).....	38	Crystal structure types. (Gruner).....	173
Capsular silica. (Burt).....	222	Crystal systems, study of. (Rogers).....	101
Cardoso, G. M. Über die Raumgruppe des Stauroliths und seine gesetzmässige Verwachsung mit Cyanit. [Review]....	240	Cupric oxide, optical and geometrical properties of (Posnjak, Tunell).....	101
Carminite from Mexico and Colorado. (Foshag).....	103	Cupric sulfates, basic and normal, optical and geometrical properties of. (Posnjak, Tunell) ..	101
Carobbi, G.....	387	Cyanite.....	377
Celestite in central Ontario. (Fairbairn).....	286	Dahllite, from St. Paul's Rocks. (Washington).....	369
Celestite, method of analysis....	288	Dana's Manual of Mineralogy. (Ford) [Book review.].....	489
Celestite (occurrence).....	410	Density and index of glass applied to determination of imitation gems. (Bannister).....	243
Celsian, associate of gillespite..	320	Determination of minerals under the microscope. (Evans) [Book review.].....	241
Chalcocite crystals, new form....	310	Diamonds and diamond mines in S. Africa. (English).....	105
Chile-loeweite. (Wetzel).....	244	Diamond, piezo-electric effect of. (Wooster).....	40
Chondrodite.....	463	Diopside, optical data.....	30
Chromite, mineral and chemical composition. (Fisher).....	341	Dipyrite and associated contact minerals, Franklin Mts., Texas. (Lonsdale).....	26
Chromloeweite. (Wetzel).....	388	Discredited species.....	42
Chudoba, K.....	439		
Clinton, H. G. Vashegyite and barrandite in Nevada.....	434		
Concentric textures at Colquijirca. (McKinstry).....	431		
Connolly, J. P. and O'Harra, C. C. Mineral wealth of Black Hills. [Book review].....	437		
Cooper, R. A.....	339		

- Dispersion of minerals.** (Winchell)..... 125
- Dolomite, polysynthetic twinning in.** (Rogers)..... 101, 245
- Domeykite group, x-ray study of.** (Ramsdell)..... 102, 188
- Données numériques de cristallographie et de minéralogie. (Spencer) [Book review.]... 76
- Double variation method of refractive index determination.** (Emmons)..... 414
- Drewite. (Field, Kindle)..... 440
- Dumortierite, occurrence near Quartzsite, Ariz.** (Wilson)... 373
- Duparc, L..... 78
- Eakle, A. S. Probertite, a new borate**..... 427
- Eckermann, H. von..... 440
- Einführung in die Kristallstrukturlehre. (von Wolff) [Book review.]... 277
- Eisenbrucite..... 42
- Elements of Mineralogy. (Rutley) [Book review.]..... 488
- Emmons, R. C. Double variation method of refractive index determination**..... 414
- **Modified universal stage.** 441
- **Set of thirty immersion media.**..... 482
- [Book review.]..... 277
- Ending of chemical adjectives in isomorphous minerals. (Schaller)..... 102
- English, G. L. Diamonds and diamond mines in S. Africa... 105
- Etching, natural, of detrital garnet. (Bramlette)..... 336
- Evans, J. W. Determination of minerals under the microscope. [Book review.]..... 241
- Fairbairn, H. W. Celestite in central Ontario**..... 286
- Fairbanks, E. F. Photo-luminescence of minerals..... 102
- Fairbanks and others. Laboratory investigation of ores. A symposium. [Book review.]..... 385
- Fairchild, J. G. Base exchange in artificial autunites**..... 265
- Ferri-muscovite. (Wahl)..... 440
- Ferri-orthoclase. (Wahl)..... 440
- Ferrothorite. (Lacroix)..... 78
- Fersman, A. E..... 440
- Field, R. M..... 440
- Finály, I. de. and Koch, S. Fülöppite, new mineral of the plagiomite-semseyite group from Hungary..... 312
- Fisher, L. W. Chromite, mineral and chemical composition**... 341
- Fluoborite. (Bauer, Berman)... 103, 165
- Fluorescence, exhibit illustrating.** (Gordon)..... 362
- Fluorescence, list of minerals showing..... 367
- Fluorescence of minerals in ultraviolet rays. (Spencer)..... 33
- Ford, W. E. Dana's Manual of Mineralogy. [Book review.]... 489
- Foshag, W. F. Carminite from Mexico and Colorado..... 103
- Foye, W. G. Manganotantalite from Connecticut..... 75
- Fragments, determination of, with polarizing microscope. (Rogers)..... 102
- Franklin minerals, paragenetic classification of.** (Palache)... 1, 105
- Franklin minerals, comparison with Langban ore deposits.** (Palache)..... 43, 105
- Franklin mountains, Texas, dipyrrite and associated minerals from.** (Lonsdale)..... 26
- Franklin zinc deposits, origin of** (Tarr)..... 207
- French Creek mines, passing of. (Gordon)..... 104
- Fülöppite, new mineral of plagiomite-semseyite group. (de Finály, Koch)..... 312
- Gabriel, A. and Cox, E. P. Stain-**

- ing method for quantitative determination of certain rock minerals 290
- Gaubert, P. 42
- Gearksutite from Virginia. (Henderson).** 281
- Gehlenite (melilite group) 405
- Genesis of some types of feldspar from granite pegmatites. (Anderson) [Review.] 241
- Germanium in minerals. 37
- Gillespite, properties of, and associated minerals. (Schaller).** 319
- Glomero-granular texture. 312
- Gold at Torquay, Devonshire. (Russell). 164
- Gordon, S. G. Exhibit illustrating fluorescence at the Academy of Natural Sciences of Philadelphia.** 362
- Llalagua phosphates. 104
- Passing of the French Creek mines. 104
- Graminite. 42
- Groves, A. W. and Maurant, A. E. Inclusions in apatite of igneous rocks 243
- Gruner, J. W. Crystal structure types** 173
- Structural reasons for oriented intergrowths in some minerals 227
- Structure of boracite. 102
- Structures of sulfides and sulfosalts 470
- Book reviews. 240, 241, 277, 278
- Guild, F. N. Copper pitch ore.** 313
- Gypsum 59
- Halite-anhydrite intergrowths. (Schaller) 106
- Haltom, W. L. Magnet Cove, Ark., and vicinity. 484
- Harwood, H. F. 164
- Hawkes, L. A partially fused quartz-feldspar rock, and 'glomero-granular' texture. 312
- Hawkins, A. C. New and unusual N. Jersey mineral occurrences. 106, 309
- Book review. 117
- Hedenbergite (analysis and optical properties) 321
- Henderson, E. P. Gearksutite from Virginia.** 281
- Hesnard, E. E., memorial of. (Landes) 202
- Hills, V. G. A unique formation of satin spar. 200
- Hoeferite. 42
- Holmes, A. and Harwood, H. F. Tholeiite dikes of England 164
- Hunt, W. F. Book reviews. 76, 163, 241, 385, 437, 488, 489
- and Kraus, E. H. Mineralogy. [Book review.] 117
- Huntsinger, H. A. Monochromatic light source.** 329
- Hydrophilite, notes on. (Slawson) 160
- Iimori, S. 440
- Illinois record copper erratic. (Crook).** 104, 119
- Imitation gems, determination of, with reference to density and index of silicate glasses. (Bannister) 243
- Immersion media, set of. (Emmons).** 482
- Immersion melts of high refraction. (Barth).** 358
- Interfacial tension of crystal faces. (Miller) 102
- Jakob, J. Anleitung zur chemischen Gesteinsanalyse. [Book review.] 76
- Joffe, A. F. Physics of crystals. [Book review.] 277
- Johansson, K. 42
- Julienite. (Schoep) 41
- Kargin, V. 79
- Kerr, P. F. An artificial gem stone isomorphous with spinel.** 256

Kerzinite. (Schadlun).....	41	Maghemite. (Wagner).....	387
Klockmannite. (Ramdohr).....	41	Magmas, temperatures of. (Lar-	
Kindle, E. M.....	440	sen).....	81
Kinoshita, K.....	388	Magnet Cove, Ark., and vicinity,	
Koch, S. Fülöppite.....	312	and list of minerals. (Haltom)	484
Kraus, E. H. and Hunt, W. F.		Mangandiaspore. (Chudoba)....	439
Mineralogy. [Book review.]..	117	Manganese minerals of hydro-	
Krenner, J.....	78, 79	thermal vein. (Ross, Shannon)	106
Krystallographische und struk-		Manganese silicate, Hökø mine.	
turtheoretische Grundbegriffe.		(Kinoshita).....	388
(Niggli) [Book review.].....	204	Manganotantalite (Foye).....	75
Kurbatov, I.....	79	Marshall, P. New mineral in	
Laboratory investigation of ores.		phonolites of N. Zealand.....	312
A symposium. (Fairbanks and		Martin, N.....	40
others) [Book review.].....	385	McKinstry, H. E. Interpretation	
Lacroix, A.....	78	of concentric textures at Col-	
Landes, K. K. Memorial of E. E.		quijirca, Peru.....	431
Hesnard.....	202	——— On naming minerals.....	197
——— Strontium occurrence near		Melilite group, composition of.	
LaConner, Wash.....	408	(Berman).....	389
Långban, Sweden, ore deposits—		Meteoric stone of Lake Brown,	
comparison with Franklin, N.		Western Australia. (Prior)...	312
Jersey. (Palache).....	43, 105	Meteors, largest. (Science).....	201
Larnite. (Tilley).....	338	Mikroskopische Physiographie der	
Larsen, E. S. Temperatures of		Mineralien und Gesteine. (Ro-	
magmas.....	81	senbusch, Mügge) [Book re-	
———.....	42	view.].....	161
——— and Schaller, W. T. Seren-		Miller, C. E. Interfacial tension	
dibite from Warren Co., N. Y.	104	of crystal faces.....	102
Lehrbuch der Kristallphysik.		Mineral determination by absorp-	
(Voigt) [Book review.].....	386	tion spectra. (Wherry) I....	299
Leonard, R. J. Green sphalerite		Mineral determination by absorp-	
from Sonora, Mexico.....	161	tion spectra. (Wherry) II....	323
Lichty, D. M. [Book review.]...	162	Mineralogical Society of America	
Llallagua phosphates. (Gordon).	104	List of former officers.....	107
Lonsdale, J. T. Dipyrite and as-		List of members and fellows..	108
sociated contact minerals from		Officers.....	95
Franklin Mountains of Texas.	26	Proceedings of 9th annual	
——— and Tarr, W. A. Pseudo-		meeting.....	95
cubic quartz crystals from New		Mineralogical Society of England	
Mexico.....	50	(Great Britain and Ireland)	
Loseyite, new Franklin mineral.		40, 164, 243, 312
(Bauer, Berman).....	150	Minerals, additional data.....	42
Löwe, F. Atlas der letzten Linien		Minerals, new data.....	78
der wichtigsten Elemente.		Mineralogy, an introduction to	
[Book review.].....	162	the study of minerals and	
Ludwigite group. (Schaller).....	102	crystals. (Kraus, Hunt)	
		[Book review.].....	117

- Mineral wealth of Black Hills, (Connolly, O'Hara) [Review.] 437
- Mitscherlichite. (Zamboni, Carobbi)..... 387
- Monochromatic light, broad source of. (Buerger, Huntsinger)...** 329
- Monrepite. (Wahl)..... 77
- Moorite, a new mineral, and fluoborite, from Sterling Hill, N. Jersey. (Bauer, Berman)**..... 103, 165
- Morencite..... 42
- Mourant, A. E..... 243
- Mügge, O. Rosenbusch's Mikroskopische Physiographie der Mineralien und Gesteine. [Book review.]..... 161
- Müllerite..... 42
- Nahcolite. (Bannister)..... 40, 387
- Naming of minerals. (McKinstry)** 197
- Narayana Iyer, L. A. Calc-gneiss and cordierite-sillimanite gneiss of Coimbatore, Madras..... 243
- Neue mikroskopische Beobachtungen am Cubanit (chalmersit) und Überlegungen über seine lagerstättenkundliche Stellung. (Ramdohr) [Review.]..... 278
- Nevel, W. D. Topaz crystal from Maine..... 75
- Newark Mineralogical Society..... 39, 118
- New Jersey mineral occurrences, new and unusual. (Hawkins)..... 106, 309
- New minerals. 41, 77, 244, 338, 387, 438
- New York Mineralogical Club..... 38, 117, 118, 204, 205, 276, 338
- Niggli, P. Krystallographische und strukturtheoretische Grundbegriffe. [Book review.]..... 204
- Nontronite..... 42
- Oder, C. R. L. Doubly terminated quartz crystals in sandstone in Shenandoah valley..... 382
- O'Hara, C. C. and Connolly, J. P. Mineral wealth of Black Hills. [Book review.]..... 437
- Organic compounds, crystallography of. (Buckley)..... 164
- Oriented intergrowths, structural reasons for. (Gruner).....** 227
- Palache, C. Comparison of ore deposits of Långban, Sweden, with those of Franklin..... 43, 105
- Paragenetic classification of minerals of Franklin, N. Jersey..... 1, 105
- Paragenetic classification of the minerals of Franklin, N. Jersey. (Palache)..... 1, 105
- Parsons, A. L. Determination of crystallographic constants in triclinic system..... 100, 154
- Partridge, E. P. and Ramsdell, L. S. Crystal forms of calcium sulphate..... 59
- Peacock, M. A. Two circle and three circle coordinate angles. 332
- Pegau, A. A. Rutherford mines, Amelia Co., Virginia..... 105
- Periclase from Crestmore, Calif. (Rogers).....** 103, 462
- Philadelphia Mineralogical Society..... 38, 77, 163, 164, 206, 243, 276, 311, 438, 487
- Philipsborn, H. V. Beziehungen zwischen Lichtbrechung, Dichte und chemischer Zusammensetzung in der Granatgruppe. [Book review.]..... 241
- Phosphates of Llallagua tin mines. (Gordon)..... 104
- Photo-luminescence of minerals. (Fairbanks)..... 102
- Physics of crystals. (Joffe) [Book review.]..... 277
- Piezo-electric effect of diamond. (Wooster)..... 40
- Pinguite..... 42
- Plumboferrite. (Johansson)..... 42

Posnjak, E. and Tunell, G. Optical and geometrical properties of basic and normal cupric sulfate and oxide, tenorite....	101	Rhombochase. (Krenner).....	78
Potash-alum, crystallization of. (Buckley).....	244	Rimann, E.....	388
Potassium chloride, quantitative optical determination of. (Slawson).....	103, 293	Rinkolite. (Bonshtedt, Fersman)	440
Prior, G. T. Meteoric stone of Lake Brown, W. Australia....	312	Rogers, A. F. Mineral determination in crushed fragments with polarizing microscope....	101
Probertite, a new borate. (Eakle)	427	—— Periclase from Crestmore, Calif., with list of minerals from this locality	103, 462
Projection diagrams, preparation of. (Wright)	251	—— Polysynthetic twinning in dolomite	101, 245
Pseudoglaucophane. (Duparc)....	78	—— Study of crystal systems.	101
Pyrophyllite.....	378	Rosenbusch, H., Mügge, O. Mikroskopische Physiographie der Mineralien und Gesteine. [Book review.].....	161
Quantitative optical determination of potassium and sodium chlorides. (Slawson)	103, 293	Ross, C. S. and Shannon, E. V. Manganese minerals of hydrothermal vein near Sparta, N. Carolina.....	106
Quartz crystals, doubly terminated, occurring in gypsum. (Tarr)	19	Russell, A. Gold at Torquay, Devonshire, Eng.....	164
Quartz crystals, doubly terminated, in sandstone from Virginia. (Oder).....	382	Rutherford mines, Amelia Co., Virginia. (Pegau).....	105
Quartz crystals, pseudo-cubic, from New Mexico. (Tarr, Lonsdale)	50	Rutley, F. Elements of Mineralogy. [Book review.].....	488
Quartz-feldspar rock, partially fused. (Hawkes).....	312	Sarcolite (melilite group).....	405
Quartz pseudomorphs from Paterson, N. Jersey. (Schaller). . .	100	Satin spar formation, unique. (Hills).....	200
Ramdohr, P. Neue Mikroskopische Beobachtungen am Cubanit und Überlegungen über seine lagerstättenkundliche Stellung. [Book review.].....	278	Schadlun, N. A.....	41
——	41	Schaller, W. T. Introduction to "Base exchange in artificial Autunites".....	265
Ramsdell, L. S. X-ray study of domeykite group.....	102, 188	—— Crystallography of quartz pseudomorphs from Paterson, N. Jersey.....	100
—— and Partridge, E. P. Crystal forms of calcium sulphate.	59	—— Ending of chemical adjectives in isomorphous minerals	102
Refractive index determination; double variation method. (Emmons)	414	—— Halite-anhydrite intergrowths.....	106
Renardite. (Schoep).....	244	—— Ludwigite group.....	102
		—— Properties and associated minerals of gillespite	319
		—— and Larsen, E. S. Serendibite, Warren Co., N. Y.....	104
		Schoep, A.....	41, 244

Serendibite from Warren Co., N. Y. (Larsen, Schaller).....	104	als. (Gruner).....	222
Shannon, E. V. and Ross, C. S. Manganese minerals of hydrothermal vein.....	106	Sulfides and sulfosalts, structures of. (Gruner).....	470
—— and Short, M. N. Violarite.....	103	Symmetry, devices and models for demonstration of. (Whitlock).....	101
Shannonite. (Tilley).....	42	Szaibelyite and camsellite. (Winchell).....	48
Short, M. N. and Shannon, E. V. Violarite, rare nickel mineral.....	103	Szomolnokite. (Krenner).....	79
Sillimanite.....	378	Takizolite. (Iimori, Yoshimura).....	440
Simpson, E. S.....	340	Tanatar, J. J.....	79
Slawson, C. B. Notes on hydrophilite.....	160	Tanatarite.....	79
—— Quantitative optical determination of potassium and sodium chlorides.....	103, 293	Tanteuxenite. (Simpson).....	340
Sodium bicarbonate, Nahcolite. (Bannister).....	40	Tarr, W. A. Doubly terminated quartz crystals occurring in gypsum.....	19
Sodium chloride, quantitative optical determination of. (Slawson).....	103, 293	—— Origin of zinc deposits at Franklin and Sterling Hill, N. Jersey.....	207
Soil mineralogy. (Burt) [Book review.].....	163	—— and Lonsdale, J. T. Pseudo-cubic quartz crystals from N. Mexico.....	50
Spencer, L. J. Bismutotantalite.....	312	Temperatures of magmas. (Larsen).....	81
—— Données numériques de cristallographie et de minéralogie.....	76	Tenorite. (Posnjak, Tunell).....	101
—— Fluorescence of minerals in ultra-violet rays.....	33	Tephroite, Mn-Al spinel. (Ross, Shannon).....	106
Spessartite garnet of Avondale, Penna. (analysis).....	311	Thermokallite. (Bannister).....	40
Sphalerite, green, from Mexico. (Leonard).....	161	Tholeiite dikes of north England. (Holmes, Harwood).....	164
Staining method for quantitative determination of certain rock minerals. (Gabriel, Cox).....	290	Tilley, C. E.....	42, 338
Steiger, G.....	42	Topaz, large crystal from Maine. (Nevel).....	75
Steinwachs, E.....	438	Tourmaline in sediments, appearance of. (Brown).....	104, 238
Sterling Hill, N. Jersey, zinc deposit.....	207	Triclinic system, determination of crystallographic constants of. (Parsons).....	100, 154
Strock, L. Spessartite garnet of Avondale, Penna.....	311	Tunell, G. Basic and normal cupric sulfates and cupric oxide.....	101
Strontianite, occurrence.....	411	Twinning in dolomite. (Rogers).....	101, 245
Strontium occurrence, LaConner, Wash. (Landes).....	408	Über die Raumgruppe des Stauroliths und seine gesetzmässige Verwachsung mit Cyanit. (Cardoso) [Review.].....	240
Structural reasons for oriented intergrowths in some miner-			

Universal stage, modified. (Emmons).....	441	Wherry, E. T. New data on atomic dimensions.....	54
Unusual college monument. (Bosnine).....	200	——— Book review.....	204
Usbekite (Kurbatov, Kargin)...	79	Whitlock, H. P. Devices and models for demonstration of symmetry.....	101
Valentine, W. G. Ore body at Cananea, Mexico.....	38	Whitneyite.....	190
Vashegyite and barrandite in Nevada. (Clinton).....	434	Wilkeite.....	465
Violarite, rare nickel mineral. (Short, Shannon).....	103	Wilson, E. D. Occurrence of dumortierite near Quartzsite, Ariz.....	373
Voigt, W. Lehrbuch der Kristallphysik. [Book review.].....	386	Winchell, A. N. Camsellite and szaibelyite.....	48
Vonsenite (ludwigite group).....	102	——— Dispersion of minerals... ..	125
Wagner, P. A.....	387	——— Book review.....	161
Wahl, W.....	77, 440	Wolff, F. von. Einführung in die Kristallstrukturlehre. [Book review.].....	277
Washington, H. S. Dahllite from St. Paul's rocks.....	369	Wooster, W. A.....	40
——— [Book review.].....	76	Wright, F. E. Preparation of projection diagrams.....	251
Wavellite, composition of.....	105	Yoshimura, J.....	440
Wayland, E. J. and Spencer, L. J. Bismutotantalite, new mineral from Uganda.....	312	Zambonini, F.....	387
Wetzel, W.....	244, 388	Zinc deposits at Franklin and Sterling Hill, N. Jersey, origin of. (Tarr).....	207
Wherry, E. T. Mineral determination by absorption spectra.....	299, 323		

